

NASA CR-145143

(NASA-CR-145143) NOISE CHARACTERISTICS OF
UPPER SURFACE BLOWN CONFIGURATIONS.

N78-10091

EXPERIMENTAL PROGRAM AND RESULTS Final
Report (Lockheed-Georgia Co., Marietta.)

Unclass

532 p HC A23/MF A01

CSCL 20A G3/07

50776

Noise Characteristics of Upper Surface Blown Configurations; Experimental Program & Results

by W. H. Brown, N. Searle, D. F. Blakney
A. P. Pennock, and J. S. Gibson

October 1977

Prepared under Contract No. NAS1-13870 by
LOCKHEED-GEORGIA COMPANY
Marietta, Georgia 30063 for



National Aeronautics and
Space Administration



1. Report No. NASA CR-145143		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Noise Characteristics of Upper Surface Blown Configurations; Experimental Program and Results.				5. Report Date October 1977	
				6. Performing Organization Code	
7. Author(s) W. H. Brown, N. Searle, D. F. Blakney, A. P. Pennock, and J. S. Gibson				8. Performing Organization Report No. LG77ER0198	
				10. Work Unit No.	
9. Performing Organization Name and Address Lockheed-Georgia Company Marietta, Georgia 30063				11. Contract or Grant No. NAS1-13870	
				13. Type of Report and Period Covered Final Report	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546				14. Sponsoring Agency Code	
15. Supplementary Notes Contract Monitor - W. C. Sleeman, Jr., NASA Langley Research Center, Hampton, Virginia 23665					
16. Abstract An experimental data base has been developed from model upper surface blowing (USB) propulsive lift system hardware. While the emphasis was on far-field noise data, a considerable amount of relevant flow field data were also obtained. The data were derived from experiments in four different facilities resulting in: (1) small-scale (typical 5.08 cm nozzle diameter) static flow field data, (2) small-scale static noise data, (3) small-scale simulated forward speed noise and load data, and (4) limited larger-scale (by a factor of 2.5) static noise flow field and load data. All of the small-scale tests used the same USB flap parts. Operational and geometrical variables covered in this test program included jet velocity, nozzle shape, nozzle area, nozzle impingement angle, nozzle vertical and horizontal location, flap length, flap deflection angle, and flap radius of curvature. Static flow field and performance data include nozzle efficiencies, velocity and turbulence profiles, turbulence spectra and correlations, wing/flap surface oil flow photographs, Schlieren photography, static and fluctuating flap surface pressures, and lift, drag and thrust. Far-field acoustic data include noise levels, spectra, and directivities for the previously mentioned operational and geometrical parameters, as well as scaling, forward speed, and noise reduction effects. A limited amount of near-field (simulated fuselage and wing location) noise data are also included.					
17. Key Words (Suggested by Author(s)) Aircraft Noise, Propulsive-Lift System Noise, Upper Surface Blowing, USB Noise, Flap Noise, Jet Interaction Noise, Forward Speed Effects, USB Flow Field, USB Turbulence			18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 530	22. Price*		

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FOREWORD

This document is submitted in accordance with the requirements of NASA Contract NAS1-13870, Exploratory Studies of the Noise Characteristics of Upper Surface Blown Configurations. W. C. Steeman, Jr., is the NASA Langley Contract Monitor and J. S. Gibson is the Lockheed-Georgia Project Manager.

The final technical reports of this program comprise three volumes. CR-2918 is a summary of the entire program. CR-145143 (this volume) covers the experimental portions of the program and CR-2812 covers the analytical work.

SUMMARY AND CONCLUSIONS

This document contains the USB noise and flow field/performance data base resulting from the experimental program under the contracted project. The flow field/performance data were developed to better understand noise characteristics and noise generation mechanisms in the flow field. Data were obtained from four test facilities: (1) the Aeroacoustic Flow Facility, (2) Anechoic Room, (3) Anechoic Wind Tunnel, and (4) Acoustic and Performance Test Facility. The first three facilities utilized small models, all at the same scale, while the models used in the last facility were 2.37 times as large. All data were taken under static freestream conditions except in the wind tunnel, where the freestream velocity varied from 0 to 62 m/sec.

While the facilities (Section 2.0) were used for both flow field and noise data acquisition, the data presentation in this report is divided into flow field/performance data (Section 3.0) and acoustic data (Section 4.0). A summary of major conclusions in each of these two areas is given in the following paragraphs.

Flow Field and Performance Conclusions

- o The ratio of flow length to a modified hydraulic diameter based on the jet perimeter exposed to mixing is a good correlation parameter for the ratio of peak velocity in the trailing edge wake to the nozzle exhaust velocity.

- o Turbulence intensity in the trailing edge wake is significantly decreased (20% to 25%) as flow impingement angle and flow length increase. Slight decreases in turbulence intensity result from increasing flap deflection and from moving the nozzle toward the flap. A slight increase in turbulence accompanies an increase in flap radius.
- o Flap deflection increases edge roll-up and the thickness of the flow, and also greatly increases the thickness and the inward pinching of some trailing edge velocity contours.
- o For practical USB configurations, the jet flow approximates two-dimensional behavior only at midspan.
- o The spanwise distribution of fluctuating surface pressure at the trailing edge peaks where the inward flow of entrained air scrubs the wing surface, illustrating the point that the lateral entrained air has significant influence on fluctuating surface pressures.
- o Flow visualizations and mean velocity profiles for the large- and small-scale models are similar when (1) the surface oil flow photographs are scaled directly with linear dimensions and (2) the mean velocity profiles are normalized to peak velocity and to the flow thickness.
- o Static performance is improved by using the QCSEE variable-geometry nozzle, which has side opening doors to increase flow spreading. For a 30° flap deflection, flow turning angles were greater than 20° with the side doors closed and greater than 25° with the doors open.

- o Reducing nozzle impingement angle below 20° reduces the turning angle, but increasing the impingement angle reduces turning efficiency.

Acoustics Conclusions

- o The directivity of the radiated noise field is controlled by the direction in which the flow leaves the flap trailing edge.
- o The USB flow path length from the nozzle to the flap trailing edge is the prime geometric parameter controlling the frequency of the generated noise (i.e., longer flow path, lower peak frequency).
- o The cross-sectional shape of the nozzle exerts a considerable influence on the radiated noise field. This influence is felt in the mid-frequency range, around the peak one-third octave band, and amounts to a maximum decrease of some 6dB for an increase in nozzle aspect ratio from 1 to 8.
- o The effect of nozzle impingement angle on noise is similar to that of nozzle aspect ratio in that nozzle configurations which enhance spanwise spreading of the jet tend to have lower peak noise levels.
- o The use of nozzle variable-geometry side doors to promote spanwise spreading tends to increase noise a little. It is suspected that this increase is caused by the increased effective nozzle exit perimeter. Presumably, if the doors could be designed so that the bottom edges remained sealed when open, some noise benefit could be gained.
- o Nearfield/farfield correlations indicate that the strongest noise source is on the centerline close to the flap trailing edge, i.e., in the region of highest shear.

- o Scaling of farfield acoustic data can be adequately accomplished by changing the sound pressure levels by $10 \log$ (ratio of nozzle areas) and shifting the frequency by the ratio of the linear scales, provided the wing/flap is also scaled in the same way as the nozzle.
- o The effect of nozzle size increase for a given wing/flap geometry is to increase the noise level but with no frequency shift.
- o One of the causes of the discrete frequency noise tones observed in the farfield acoustic data is apparently the feedback mechanism between the nozzle exit plane and the shock formed on the curved portion of the flap in the case of high subsonic jet exit velocities.
- o Secondary blowing from a slot on the upper surface just upstream of the flap trailing edge appears to have the potential for reducing USB noise significantly. Preliminary tests resulted in reductions of 5dB overall and even more in certain frequency ranges.
- o Replacement of the flap upper surface with porous material produces only a small reduction in flyover noise. Extending the flap trailing edge with porous material produces a small noise reduction in both the flyover and 30° sideline planes.
- o Forward speed generally decreases low-frequency noise. It has little effect at the high frequencies at most microphone locations but causes increases in high-frequency noise at microphones behind the wing.

1.0 INTRODUCTION

Upper surface blowing (USB) has shown promise of good aero-propulsive performance and relatively low noise levels, making it a potentially valuable concept for powered-lift applications to short-haul aircraft. This program was therefore undertaken to develop an appropriate data base of noise characteristics for use in the design of low-noise USB aircraft. A companion effort, under NASA Contract NAS1-13871, was also undertaken at Lockheed to provide a cruise performance data base.

The primary objective of the project was to develop an experimentally derived data base of USB noise characteristics, with emphasis on low-noise configurations. A secondary objective was to ensure that low-noise configurations were feasible and acceptable from the aircraft low-speed and cruise performance standpoints. This was accomplished (1) by ensuring that the test parameters were in reasonable and useful ranges and (2) by a separate compatibility study of the integration of good performance and low-noise characteristics into a representative aircraft design. The latter item is covered in CR-2812 along with the acoustical analysis development (also a part of the primary data base) that was performed concurrently with the basic experimental program. The contents of the present volume cover the experimental techniques and results that form the largest part of the USB noise data base.

The experimental data base includes not only noise data and trends but also extensive flow field data needed to help understand the steady and unsteady flow characteristics which control noise generation. Some of the flow field data are also used as direct inputs to the noise analysis and noise prediction programs described in CR-2812.

The primary contents of this document are presented in three major sections. Section 2 describes the experimental models, facilities, instrumentation, and data reduction. It is suggested that the reader become familiar with these before commencing a review, evaluation, or use of the results, since the experimental program involved four test facilities, two model sizes, static and simulated forward speed effects, and several data reduction techniques. Section 3 covers the flow field and aerodynamic performance data obtained in the program. Section 4 presents the acoustic data.

1.1 NOMENCLATURE

AFF	Aeroacoustic Flow Facility
A_N	Nozzle area
APF	Acoustic and Performance Test Facility
AR	Aspect ratio
AWT	Anechoic Wind Tunnel
C	Constant; wing chord
C_D	Drag coefficient; discharge coefficient
C_L	Lift coefficient
C_T	Thrust coefficient
D	Drag
D_H	Hydraulic diameter
D'_H	Modified hydraulic diameter
D_J	Drag due to jet at forward speed
$D_{J(o)}$	Static drag due to jet
D_U	Drag with jet-off
F	Frequency
F_g	Gross thrust
F_S	Strouhal number correction factor
H	Nozzle height
L	Lift
L_f	Flow length from nozzle to trailing edge
L_F	Flow length on curved portion of flap
L_J	Lift due to jet at forward speed
$L_{J(o)}$	Static lift due to jet

L_{TE}	Flow length on straight portion of flap
L_U	Lift with jet off
L_W	Flow length from nozzle to start of flap curvature
NPR	Nozzle pressure ratio
P_N	Nozzle perimeter
q_o	Freestream dynamic pressure, $\frac{1}{2} \rho V_o^2$
q_N	Nozzle dynamic pressure, $\frac{1}{2} \rho V_J^2$
QCSEE	Quiet Clean STOL Experimental Engine
QSRA	Quiet STOL Research Aircraft
R	Radius from nozzle to microphone
R_c	Flap radius of curvature
S	Wing area
S_N	Strouhal number
TE	Trailing edge of flap
U, V, W	Longitudinal, lateral, and transverse mean velocities
U_p	Peak mean longitudinal velocity
u', v', w'	Longitudinal, lateral, and transverse fluctuating velocities
V_J	Jet velocity at nozzle
V_o	Freestream velocity
V_R	Relative velocity, $V_J - V_o$
W	Nozzle width
W_F	Scrubbed width at start of straight portion of flap
W_N	Scrubbed width at nozzle
W_{TE}	Scrubbed width at trailing edge
W_W	Scrubbed width at start of curved portion of flap

X,Y,Z	Longitudinal, lateral, and transverse coordinates
X'	Distance downstream of trailing edge
X_N	Distance from wing leading edge to nozzle
Z'	Distance above surface
Z_N	Nozzle spacing from wing
λ_x, λ_z	Longitudinal and transverse length scales of turbulence
δ_f	Flap deflection angle
ΔP	Surface static pressure minus ambient pressure
θ	Angle from inlet
θ''	Angle from flap upper surface
θ_N	Impingement angle
ρ	Density
τ	Time
ϕ	Elevation angle

2.0 EXPERIMENTAL PROGRAM

The program was designed to determine the influence of configurational and operational parameters on the acoustic and high-lift performance of upper surface blowing configurations. The properties of the flow field were defined in the Aeroacoustic Flow Facility, while the acoustic properties were determined in the Anechoic Room, both using small-scale static models. High-lift performance, scale effects, and the effects of noise reduction techniques, including trailing edge blowing, were obtained from larger scale static testing at the Acoustic and Performance Test Facility. Tests for forward speed effects, as well as a limited amount of performance verification, were conducted in the Anechoic Wind Tunnel.

The three major test categories are discussed in the following sections.

2.1 SMALL-SCALE STATIC TESTS

2.1.1 Facilities

2.1.1.1 Anechoic Room - The Anechoic Room, shown in Figure 2-1, is 8.53 m high by 6.71 m by 6.10 m between the concrete walls. The walls are covered with acoustic foam wedges which provide an anechoic environment at all frequencies above 200 Hz. Subtracting the volume occupied by the wedges, which are 46 cm deep, leaves a free-field volume of 265m^3 .

Figure 2-2 presents a plan view of the facility, showing the exhaust provisions and air supply system. Up to 9.01 kg/sec of clean dry air is supplied at ambient temperature and a pressure of $6.9 \times 10^5 \text{ N/m}^2$ (100 psi). The air supply plenum chamber is wrapped with foam to prevent the external

transmission of upstream noise. The plenum extends to the center of the room to allow noise measurements both forward and aft of the model. The elevated temperature required for portions of the test was provided by the electric heater. The heater, coupled with the large muffler section, provides minimal propagation of upstream noise sources.

A cherry-picker crane provides access to the instrumentation and test installation, as is shown in Figure 2-3. The crane is stowed under an acoustically-treated shelter during testing.

2.1.1.2 Aeroacoustic Flow Facility - The Aeroacoustic Flow Facility (AFF) is a multi-purpose facility for small-scale static tests. Figure 2-4 is a view of the test area taken through the large side door of the building. The air supply plenum with a model instrumented for surface pressure measurements is seen in the right center of the photograph. A Schlieren apparatus is shown in position, and in the background, a small wind tunnel is seen in front of the control and instrumentation room.

The air supply to the facility is a 15.24-cm diameter line capable of delivering 9.1 kg/sec of clean dry air at $2.07 \times 10^6 \text{ N/m}^2$ (300 psi). Air to the plenum is supplied through a 5.08-cm regulating valve and a calibrated-nozzle flowmeter. The plenum contains an end-baffled perforated tube inlet, a 15.24-cm thick honeycomb baffle, and two smooth conical transitions, the last of which matches the inside of the nozzles described in the next section. A static pressure tap and a thermocouple mount are provided for the measurement of plenum conditions.

2.1.2 Models

The design criterion for the experimental model for the small-scale tests

was complete coverage of the ranges of the geometric variables. This was accomplished with a model, shown in Figures 2-5 and 2-6, consisting of four major parts -- the wing, the nozzle, the flap curved section, and the flap trailing edge. Eight nozzles, ten curved sections, and six trailing edges were made, as listed in Table 2-1.

The wing had a span of 50.80 cm and a basic chord, including leading edge and retracted flap, of 15.24 cm. The chord of the wing test piece, shown in Figure 2-6, was 10.31 cm. Removable filler plates in the upper surface allowed the nozzle inner lip to be set flush with the wing surface at 20%, 35%, or 50% chord. Two identical wings were made so that simultaneous tests with different flaps and nozzles could be conducted in the Anechoic Room and the Aeroacoustic Flow Facility.

The nozzle exit configurations are shown in Figure 2-7. The external nozzle profiles can be seen in Figure 2-8. All nozzles were designed to provide smooth internal flow to prevent internally generated noise. The internal contour of the aspect ratio 4 nozzle is shown in Figure 2-9. Photographs of the remaining model components are found in Figure 2-10.

Small countersunk screws, smoothed with tape or wax, were used to join the curved section to the wing and the trailing edge to the curved section. The wing/flap assembly and nozzle were attached to brackets, shown in Figure 2-11, which were mounted on the air supply plenums of the two facilities. The brackets allowed for adjustment of the wing-to-nozzle location, providing the required variations of nozzle chordwise position, vertical position, and impingement angle. The values of these variables tested are given in Table 2-2.

2.1.3 Data Acquisition and Reduction

2.1.3.1 Acoustics - The data flow can be followed in the diagram of Figure 2-12 and the actual acquisition equipment is pictured in Figure 2-13. The acoustic data in the Anechoic Room were taken using twelve B&K Model 4135 0.64-cm free-field microphones with protective grids and B&K Model 2619 FET preamplifiers. This combination was selected to provide the flattest possible frequency response over the range of frequencies desired, 100 Hz to 80,000 Hz. The analog signals were then transmitted through twelve 30-m B&K extension cables to the test control center outside the Anechoic Room, where all the remaining data acquisition equipment was located.

The extension cables were connected to a B&K Model P220-1 twelve-channel power supply. From this unit the analog signals were passed through RG58/U coaxial cables to twelve Hewlett-Packard Model 8875A data amplifiers which were used to maintain a high signal-to-noise ratio. The signals were then individually analyzed in real time using the General Radio Model 1921 Real-Time Analyzer. This unit provided digital output of SPL for each one-third octave band from 100 Hz to 80,000 Hz. The digital data were then formatted and recorded on magnetic tape for input to the bulk data reduction system. Several on-line monitoring devices were used to maintain close watch on the spectra. This equipment is also shown in Figure 2-13.

To provide accurate frequency response corrections for the analog data channels, an electrostatic actuator calibration sweep through the entire one-third octave band range of interest was performed on each individual channel. Channel in this usage refers to the microphone, preamplifier, cable, power supply, and amplifier connected together to form a complete data acquisition channel. The free-field corrections for the Model 4135 microphone

with protective grid were added to these calibrations to give twelve sets of system calibrations.

Six microphones were mounted on each of two arches, as shown in Figure 2-1. With the model mounted inverted, the arches provide 30°-elevation and fly-over measurements simultaneously. The model could also be rotated to other angular positions to obtain data in other planes.

The digital tape from the above data acquisition system was taken daily to the Flight Test Data Center and processed through the mass data reduction system, diagrammed in Figure 2-14. Card inputs were used to define the run number, Anechoic Room wet and dry bulb temperature, atmospheric pressure, and plenum temperature and pressure. These data were used for the calculation of relative humidity and nozzle exit velocity.

The output from the bulk data reduction is shown in Figure 2-14 and the generalized flow chart for the program is given in Figure 2-15.

2.1.3.2 Oil Flow Photographs - Photographs of surface oil flow patterns in the Aeroacoustic Flow Facility were taken and processed by the Lockheed Photographic/Motion Picture and Television Department. All photographs were taken from a common location which was reproduced by attaching the camera tripod to a heavy stand whose position was marked on the facility floor. The exposures were made immediately after the air flow had been shut off even though flow patterns on the surface persisted with little perceptible running for many minutes.

The surface film was a nominal 10:5:1 parts by volume mixture of titanium dioxide particles, light oil, and oleic acid, respectively. Additional oil was added for thinning as required. The mixture was applied with a

brush as appropriate for an oil-base paint, which has the same consistency. Before each run the pigmented oil was redistributed by brushing with span-wise strokes.

Illumination was supplied by a tripod-mounted movie light which was switched on only when needed. The exposures were made using a Hasselblad camera and Tri-X film. The photographs were printed on 20.3 x 25.4 cm glossy paper. A common enlarger set-up was used to preserve the commonality of the views.

2.1.3.3 Schlieren Photographs - The components of the Schlieren apparatus can be seen in Figure 2-4. The system, built for Lockheed by the John Unertl Optical Company, consists of a light source, two 25.4-cm diameter parabolic mirrors, and a receiver console. A continuous light and a pulsed light share a common apparent source defined by two orthogonal sets of knife edges. Each edge is controlled by a micrometer screw and the knife edge assembly can be rotated through 360° . The continuous light normally is used for set-up and the pulsed light for photography. Pulse durations of 0.25, 0.5, 1, 2, and 3 microseconds can be selected. The receiver consists of a knife edge assembly, a lens and shutter assembly, and a 70-mm roll film back or 10.2 x 12.7 cm sheet film.

In use, the Schlieren system was arranged as shown in Figure 2-4, with the light source near the model, a collimated beam normal to the plenum axis and through the test section, and the receiver in the opposite leg of the Z from the source. The included angles in the Z were equal and as small as practicable (about 10°) to minimize optical aberrations. The knife edge and the source slit were kept parallel to obtain maximum sensitivity. Horizontal or vertical orientations were selected to emphasize density gradients in the direction normal to the knife edge.

The photographs were made in a darkened room using both open and synchronized shutter operation. There was no distinguishable difference between the two techniques. All photographs were made using a large-format Polaroid back with ASA400 film and a one-microsecond flash.

2.1.3.4 Static Surface Pressures - Flush pressure ports in the upper surface of one configuration were used for both static and fluctuating surface pressure measurements. The flap configuration consisted of the 7.62-cm radius 60°-deflection segment followed by the 6.47-cm trailing edge. Pressure tubes were potted into holes drilled through the wing and the holes were filed flush with the upper surface. The layout of the ports is shown in Figure 2-16.

The instrumentation is shown schematically in Figure 2-17. A Statham $\pm 17.25 \text{ N/m}^2$ ($\pm 2.5 \text{ psi}$) pressure transducer was used in the scanivalve. Ambient pressure was applied to the first and last ports as the pressure reference. An Endevco bridge supply was used for transducer excitation. The output of the transducer was plotted on an X-Y recorder as a histogram by manually stepping the scanivalve while the X-axis was traversed. The pressure calibration was accomplished by adjusting the plotter to obtain a convenient trace level when a known pressure was applied to the reference port of the transducer. Data reduction consisted of reading the pressures from the plots and plotting them versus location.

2.1.3.5 Fluctuating Surface Pressures - Probe microphones inserted from the lower surface of the wing were used to measure fluctuating surface pressures. Static pressure ports along the midspan line and the trailing edge were drilled out to accept a 0.2-cm O.D. microphone probe as shown in Figure 2-18. Signals from the two microphones were treated as shown

schematically in Figure 2-19. The B&K power supply and conditioner provided basic excitation and output level control. The H-P amplifiers were subjected to a common input sound level. An H-P 3721 correlator provided auto- and space/time correlations which were plotted on an X-Y plotter.

The H-P 3721 is a digital correlator with selectable input attenuation, sample size, and delay-time increments. The correlation function is displayed on a CRT, where 100 data points are shown on an 8 x 10-cm screen. The digital output of the correlator was plotted on an X-Y plotter with a scale factor of 2.54. The resolution of the output data was one delay-time increment and 1/80 full-scale on the vertical axis.

The lack of an operable pen-lift function in the plotter made the on-line plots hard to read. The translating pen would often overshoot before coming to rest at the desired point. This problem was overcome by fairing a curve through the test points. The correlation functions plotted in Section 3 were obtained by this process.

The B&K Model 4134 microphones were fitted with B&K 0.2-cm O.D. probes 15.24 cm long. The probes were damped for optimum frequency response as recommended by the manufacturer.

2.1.3.6 Hot-Wire Velocities - Linearized constant-temperature anemometers were used to measure mean and turbulent velocities. The basic configuration is shown schematically in Figure 2-20. Variations included the substitution of an H-P 4300A RMS voltmeter as an RMS detector in place of the B&K Model 2416 voltmeter and the TP622 detector, and the use of the newer 55M01 anemometer and 55M25 linearizer. For velocity correlations, the linearizer output was input directly to the H-P 3721 correlator, and the correlator

output was plotted. The hot-wire sensors consisted of a tungsten wire 5×10^{-4} cm in diameter, copper-plated outside the 0.2-cm active length, and mounted on a DISA "Gold-Plated" probe tip with 0.3-cm prong spacing.

The linearized hot-wire anemometer was system-calibrated using a convergent nozzle and assuming isentropic flow. Plenum temperature and pressure and ambient pressure were read from calibrated instruments. The probe was inserted in the core flow from the downstream direction with the probe prongs parallel to the flow and the hot-wire normal to the flow. This minimized probe interference effects. Optimum frequency response was obtained by individually tuning the anemometer input for each probe and cable change. The linearizer was adjusted to obtain a straight-line relationship between velocity and linearizer output. The linearizer output and plotter scale were then adjusted to obtain the desired full-scale values. Linearity and full-scale readings were checked at least once each day. Turbulence intensity was calibrated by adjusting the plotter scale appropriately while substituting a fluctuating signal of known value at the RMS detector input. The position scale of the plotter was calibrated similarly. The plotter scale was adjusted at each end of the traverse using a steel scale as a reference.

Proper correlator functioning was verified by performing auto- and cross-correlations on known signals. Plotter scales were adjusted to produce a magnified copy of the correlator display.

2.2 LARGE-SCALE STATIC TESTS

The outdoor Acoustic and Performance Test Facility (APF) was used to test nozzle/wing/flap models at a larger scale than in the Anechoic Room, expanding

the scope of the program to achieve the following objectives:

- To evaluate and define significant acoustic scale effects
- To measure lift and drag loads
- To measure surface pressure fluctuations
- To measure the performance of the QCSEE nozzle
- To evaluate several noise reduction concepts, including trailing edge slot blowing.

2.2.1 Facility

The facility is designed for the simultaneous acquisition of acoustic and propulsion performance data from various nozzle and wing/flap configurations. It comprises the test rig and air system, described below, and the control room and data acquisition system, described in Section 2.2.3.

The rig is located on a concrete pad 15 m in diameter. The pad provides uniform and repeatable ground acoustic reflections. These reflection effects were determined experimentally for each acoustic measurement position and corrections for these effects were applied during the data reduction procedure, described in Section 2.2.3, to obtain free-field acoustic data.

The airflow centerline is 1.8 m above grade. To eliminate noise due to jet impingement on the concrete pad, wing/flap models are mounted with the wing span vertical. The air supply system provides an airflow of up to 8.2 kg/sec at $6.9 \times 10^5 \text{ N/m}^2$ (100 psi) and essentially ambient temperature to the test site settling tank through a 15.24-cm pipe system. With this air supply a nozzle pressure ratio of 1.5 can be obtained with, for example, a one-fifth-scale model of a TF34 nozzle.

From the settling tank, air is delivered to the test article through a 15.24-cm and/or a 10.16-cm pipe which are individually controlled. Both

systems are equipped with control valves, electrically actuated from the control room, and downstream mufflers to attenuate internally-generated flow noise. The downstream sections of both pipes were wrapped with acoustic material to prevent the transmission of internal pipe noise to the free-field.

2.2.2 Models

Three nozzles were used for the majority of the testing. They were: (1) AR-4 - A rectangular nozzle of aspect ratio 4; (2) AR-8 - A rectangular nozzle of aspect ratio 8; (3) QCSEE - A variable-geometry nozzle made to the NASA QCSEE design (this nozzle had opening side doors with three available door angles: 0° , 15° and 25°). The nozzles had nominal exit areas of 114.2 cm^2 . The QCSEE nozzle area was 114.2 cm^2 with the side doors closed, and increased in effective exit area as the doors were opened. Profiles and end views of the nozzles are shown in Figure 2-21. In addition, a circular nozzle with 244.8 cm^2 exit area was tested with the nozzle directly on the wing and off the wing in a simulated vectored thrust mode.

Limited performance testing was done using the AR-4D nozzle. This consisted of the AR-4 nozzle equipped with a 12° deflector on the top of the nozzle as shown in Figure 2-22. The deflector reduced the effective flow area to 80.6 cm^2 . Some data were also taken using a large circular nozzle with an area of 244.5 cm^2 . All nozzles except the AR-4D provided scaling correlation with the small-scale nozzles.

The wing had a chord of 61.0 cm and a span, excluding the wingtip, of 73.7 cm. Detailed descriptions of the wing and AR-4 and AR-8 nozzles may be found in the Lockheed QSRA report, Reference 1. The wing was mounted

either on a balance, described in Section 2.2.3.6, for the wing force tests, or on a pedestal when wing loads were not required. The pedestal could be rotated and was mounted on orthogonal tracks, shown in Figure 2-23. This arrangement allowed for a full range of variation of nozzle impingement angle, nozzle vertical position, and nozzle chordwise position.

A 30° and a 60° flap section were provided. Each section consisted of contoured ribs covered by an aluminum sheet. The radius of curvature was 18.1 cm and the flow length from the nozzle to the trailing edge was 51.7 cm. These were scaled to correspond to the small-scale R_c of 7.6 cm and total flow length of 21.8 cm.

A 30° flex-flap, also described in Reference 1, was used to test the effect of trailing edge blowing. This flap provided for variable trailing edge slot height and was used with various trailing edge blowing velocities. When the untreated flap tests were finished, the 30° flap section was modified to incorporate noise reduction treatments. Three treatment materials were used, as follows:

- ° Perforated plate with large holes - hole diameter = 0.3 cm, thickness = 0.08 cm, open area = 37%
- ° Perforated plate with small holes - hole diameter = 0.11 cm, thickness = 0.06 cm, open area = 31%
- ° Feltmetal - nominal flow resistance = 20 rayls, thickness = 0.09 cm

Three treatment locations, shown in Figure 2-24, were tested-

- ° As the upper surface of the whole flap
- ° As the upper surface of the downstream half of the flap
- ° As a trailing edge extension.

When used as surface treatments the treatment material replaced the solid skin, and the cavity between the upper and lower surfaces of the flap was not filled. Surface treatments and trailing edge extensions were tested in combination. In addition to these treatments, a flap with airfoil-shaped vanes along the trailing edge was tested. The vanes were 0.5 cm high, 2.54 cm long, 7.6 cm apart, and were aligned with the flow. This flap is shown in Figure 2-25.

To better simulate the QCSEE wing, a leading edge extension, pictured in Figure 2-26, was added to the standard wing section described above.

2.2.3 Data Acquisition and Reduction

Most of the data acquisition in the large-scale tests was done in the Test Control Room, Figure 2-27, where the acoustic and performance data acquisition systems and air supply system controls are located.

2.2.3.1 Acoustics - The acoustic data on the outdoor rig were taken using basically the system described for the Anechoic Room in Section 2.1.3.1. Eleven B&K Model 4135 microphones and Model 2619 preamplifiers were used. They were powered by a KEPCO HB2AM 200-VDC power supply and a KEPCO SC-18-AM-200 6-VDC power supply. A free-field correction was applied to the microphones to account for the use of B&K UA 2037 foam windscreens, used to prevent unwanted wind noise. To be certain that the effective range of the windscreens was not exceeded, testing was halted when the wind velocity was greater than 5 m/sec.

The microphones were positioned on a movable arch at a 6.1-m radius, as shown in Figures 2-28 and 2-29. The arch rotates about the nozzle centerline from 90° below the vertically mounted wing to 90° above it. The microphones were approximately 60 m from the test control room. The cable used

to transmit the analog data over this long distance was a standard four-wire shielded conductor, which had a very large high-frequency drop-off. Lockheed-built line-driver amplifiers were used to power the cable and provide a flat frequency response (± 0.5 dB from 100 Hz to 80,000 Hz). The signals were processed as described in Section 2.1.3.1. The electrostatic actuator calibration described in Section 2.1.3.1 was performed on each channel to obtain the true frequency response of each. The mass data reduction procedure and program was the same as that used for the Anechoic Room and described in Section 2.1.3.1. The output of the bulk data reduction program was also the same as is shown in Figure 2-14.

2.2.3.2 Fluctuating Surface Pressures - Fluctuating pressures on the flap surface were measured using four Kulite Model LQ-30-125-10F transducers powered by a 6-volt dry cell battery. The transducers were glued to the flap surface at the locations shown in Figure 2-30, using Eastman 910 glue. Modeling clay was used to fair the step from the flap surface to the top of the transducer.

The transducers were initially calibrated by applying a static pressure differential on the transducer in a vacuum chamber. The static pressure differential was converted to the equivalent dB value, which, combined with its associated transducer voltage output, provided the required calibration value. The output of the Kulites was acquired and processed in the same manner as the microphone output previously discussed.

2.2.3.3 Hot-Wire Velocities - A linearized hot-wire anemometer system was used at the APF in much the same way as is described in Section 2.1.3.6. Significant differences are that the data were hand-recorded from the H-P voltmeters for a number of fixed probe locations which were manually set. The data were plotted manually.

2.2.3.4 Velocity Rake Profiles - Wake velocity profiles were measured using a 73-probe pressure rake consisting of tubes with an O.D. of 0.126 cm and a wall thickness of 0.020 cm, spaced 0.64 cm apart. The total pressures from the probe were surveyed by two scanivalves and input to the Pulse Code Modulation (PCM) system for processing with the performance data shown in Figure 2-31.

The data reduction program used measured nozzle thrust from a load cell, nozzle mass flow from an orifice plate, and nozzle pressure and temperature measurements to compute nozzle exit velocity. The program also computed rake velocity based on rake total pressure and nozzle conditions. The ratio of rake velocity to nozzle velocity was listed in the printed output along with the basic thermodynamic and performance data.

2.2.3.5 Oil Flow Patterns - Flow visualizations using surface oil flow were made at the APF essentially as they were in the AFF (described in Section 2.1.3.2). Natural lighting and a 6 x 7 cm camera were used. Off-the-wing and deflector nozzle configurations were photographed from relatively long range so that the perspective would be clear. The other configurations were photographed from near positions selected to best show the flow patterns near the trailing edge.

2.2.3.6 Performance - Figure 2-32 shows a schematic of the air piping system and the test rig performance instrumentation. The axial and vertical thrust of the nozzle were measured with Toroid Model 36-233 load cells of 4450N capacity. The forces on the wing/flap system were measured using a Lockheed five-component pedestal-mounted balance, shown in Figure 2-33. It provided the following outputs:

- Lift to $\pm 2200\text{N}$ design load
- Drag to $\pm 2200\text{N}$ design load
- Pitching moment to 400 N-m design load
- Rolling moment to 2000 N-m design load
- Yawing moment to 2000 N-m design load

All temperature measurements were made using chromel-alumel thermocouples. The nozzle total pressure was obtained from four total pressure probes, manifolded to give an average reading. Nozzle static pressure was provided by four manifolded static probes. These pressures as well as the others shown in Figure 2-32 were taken using various models of Statham pressure transducers. The wake data were taken using a 73-probe rake, described in Section 2.2.3.4, plumbed into two 48-port Model 48J9 scanivalves.

The performance data were recorded by the data acquisition system diagrammed in Figure 2-31. The output PCM analog tape was then taken to the Flight Test Data Center where it was processed through the Aero/Propulsion data reduction system shown in Figure 2-34. The output consisted of the performance parameters, given in Figure 2-34, in tabular form.

2.3 WIND TUNNEL TESTS

Wind tunnel tests were conducted to determine the effects of forward velocity on noise generation and propagation, local velocities, and forces.

2.3.1 Facility

The tests were conducted in the Lockheed Anechoic Wind Tunnel. The basic anechoic room is 3.4 m long by 3.4 m wide by 5.2 m high between the wedge

tips. The interior is lined with fiberglass anechoic wedges which provide an echo-free environment at all frequencies above 100 Hz. An open mesh floor, suspended from the walls, provides access to the model and instrumentation.

A planview schematic of the facility is shown in Figure 2-35. Starting from the left, air is drawn into the intake (Figure 2-36(a)), through the honeycomb and screens to the contraction section, across the anechoic room to the collector (Figure 2-36(b)), through the diffuser, the two right-angle corners with turning vanes, and the duct silencers to the transition section (Figure 2-36(c)). The facility is powered by an ejector whose primary and entrained flows are diffused through the 17.1-m long muffler/diffuser section shown on the right of Figures 2-35 and 2-36(c).

To prevent the transmission into the test section of the noise generated by the 8.6-cm diameter jet which powers the ejector, the double walls of the floor, sides, and roof of the tunnel between the collector and the ejector are filled with dry sand. For further attenuation the duct is lined with polyurethane foam, acoustically treated turning vanes are installed, and Industrial Acoustics Company quiet-duct silencers are installed.

The air supply to the ejector comes from the main $2.07 \times 10^6 \text{ N/m}^2$ (300 psi) compressor which supplies air to all research center facilities. The model air supply comes from the $0.69 \times 10^6 \text{ N/m}^2$ (100 psi) port of the main compressor.

For minimum blockage in the working section, the air supply ducting for

the model jet is installed axially in the intake/contraction section as can be seen in Figures 2-35 and 2-36(a).

2.3.2 Models

2.3.2.1 Acoustic Tests - The model used in the wind tunnel acoustic tests is pictured in Figure 2-37. The components are the nozzle, the wing, the flap curved section, and the flap trailing edge. The nozzle and wing were fabricated specifically for this test; the flap components came from the small-scale static program.

The nozzle duplicated the small-scale aspect ratio 2 nozzle tested in the Anechoic Room and Aeroacoustic Flow Facility. Its small size, 10.13 cm^2 , gave large ratios of freestream area to nozzle area and of microphone distance to equivalent nozzle diameter. The impingement angle was 20° , the nozzle was placed at 20% chord, and the wing was set at 0° angle of attack.

The wing was built to the same design as the wings used in the Anechoic Room and Aeroacoustic Flow Facility except for the addition of a rounded leading edge. It was mounted from one end (Figure 2-38) instead of two, to minimize the flow obstruction. An airfoil-shaped fairing was attached to the supported end of the wing to isolate the support structure from the freestream and to simulate the effects of the fuselage on noise and flow.

The curved flap sections selected were the 30° and 60° sections with a radius of curvature of 5.08 cm. The radius, the smallest used in any phase of the program, was selected because the largest effects of forward speed were expected with the sharpest turning of the flow. The

trailing edge sections were 3.81 cm long for the 60° flap and 6.47 cm long for the 30° flap. These combinations, with the nozzle placed at 20% chord, provided a total flow length of 16.69 cm.

2.3.2.2 Force and Flow Field Tests - The model used in the force and flow field tests in the wind tunnel was the same as that used in the acoustic tests except that the wing was supported from the nozzle through a three-component balance instead of being supported from the wingtip. Figure 2-39 shows the installation for the flow field test. The wing position was adjusted to obtain a minimum clearance from the nozzle without fouling the balance. The rake and exposed ironwork were removed for the force tests.

Flap deflections of 30° and 60° were tested in both programs. The associated radii and trailing edge lengths were:

	$\delta_f, ^\circ$	R_c, Cm	L_{te}, Cm
Force Test	30	5.08	6.48
	60	5.08	3.81
Flow Field Test	30	5.08	6.48
	60	10.16	3.81

2.3.3 Data Acquisition and Reduction

2.3.3.1 Acoustics - The farfield acoustic data were taken with the acquisition procedure and equipment described for the Anechoic Room in Section 2.1.3.1. There were six microphones in the flyover plane on a 2.4-m radius at angles from the nozzle centerline of 75°, 90°, 105°, 120°, 135°, and 150°, and three microphones in the 30° elevation plane

at angles of 120° , 135° , and 150° . The farfield microphones were B&K Model 4135 with Model 2619 preamplifiers. There were also three near-field microphones, 0.32-cm B&K Model 4138 with Model 2619 preamplifiers, mounted in the wingtip fairing, to measure nearfield noise levels for fuselage noise and cabin noise estimates.

The microphone signals were converted to one-third octave band SPL spectra and recorded on digital magnetic tape. The tapes were reduced as described in Section 2.1.3.1.

Nearfield noise in the trailing edge area was recorded using the three lower B&K Model 4133 1.27-cm microphones of Figure 2-38; the upper six microphones in the figure are not reported herein. The lower microphones were moved successively from the centerline to two other spanwise locations, each 5 cm farther to the right from the centerline. Trailing edge noise was also recorded with a probe microphone, B&K Model 4133 with a B&K probe, located as shown in Figure 2-38.

The trailing edge noise data went through the same cabling and amplifiers as the other acoustic data but were recorded on an Ampex FR1300 tape recorder for further processing. The data from these microphones were played back with the data from the flyover 90° farfield microphone through a B&K Model 3721A correlator to obtain correlations between the farfield microphone and each nearfield microphone.

2.3.3.2 Flow Field - Trailing edge velocity contours were measured with the rake installation shown in Figure 2-39. Figure 2-40 shows at the top the complete probe pattern and at the bottom the effective pattern, with the unused probes not shown and all vertical rows on the same side of the centerline.

The rake pressures were fed through a scanivalve to a stripchart recorder, which plotted them as a bar graph. Local velocity and the ratio of the local velocity to the jet velocity at the nozzle were calculated from the stripchart readings and plotted along the rows of probes. The intercepts on the probe rows at each 0.1 interval of velocity ratio were then spotted in on the rake outline. From these points, and the further knowledge that in certain cases a given contour did not intercept a given row of probes, estimated velocity ratio contours were drawn.

2.3.3.3 Performance - The outputs of the three strain gages of the balance (lift, drag, and pitching moment) were read on a digital millivoltmeter and converted to forces and moments by a small computer program. The wind tunnel and nozzle data were read on standard instrumentation. All data were hand-recorded.

NOZZLES		FLAP CURVED PORTIONS			FLAP TRAILING-EDGE LENGTHS	
SHAPE	(AREA)	R_c		δ_f	L_{TE}	
	cm ²	cm	(IN.)	DEGREES	cm	(IN.)
AR 8 SLOT	(20.25)	5.08	(2)	30	3.81	(1.5)
CIRCULAR	(20.25)	5.08	(2)	45	6.47	(2.55)
AR 4 SLOT	(20.25)	5.08	(2)	60	8.45	(3.33)
QCSEE	(21.54)	7.62	(3)	30	9.14	(3.60)
D SHAPE	(10.12)	7.62	(3)	45	10.46	(4.12)
ELLIPSE	(10.12)	7.62	(3)	60	11.78	(4.64)
AR 2 SLOT	(10.12)	10.16	(4)	30		
CIRCULAR	(10.12)	10.16	(4)	45		
		10.16	(4)	60		
		∞		0		

TABLE 2-1. MODEL PARTS

NOZZLE CHORDWISE LOCATION

$x_N/c \sim \% \text{ CHORD}$

20
35
50

NOZZLE VERTICAL POSITION

$Z \sim \text{cm (in.)}$

0 (0)
1.58 (0.625)

NOZZLE IMPINGEMENT ANGLE

$\theta_N \sim \text{DEGREES}$

0
10
20
30
40

TABLE 2-2. NOZZLE POSITION VARIATIONS

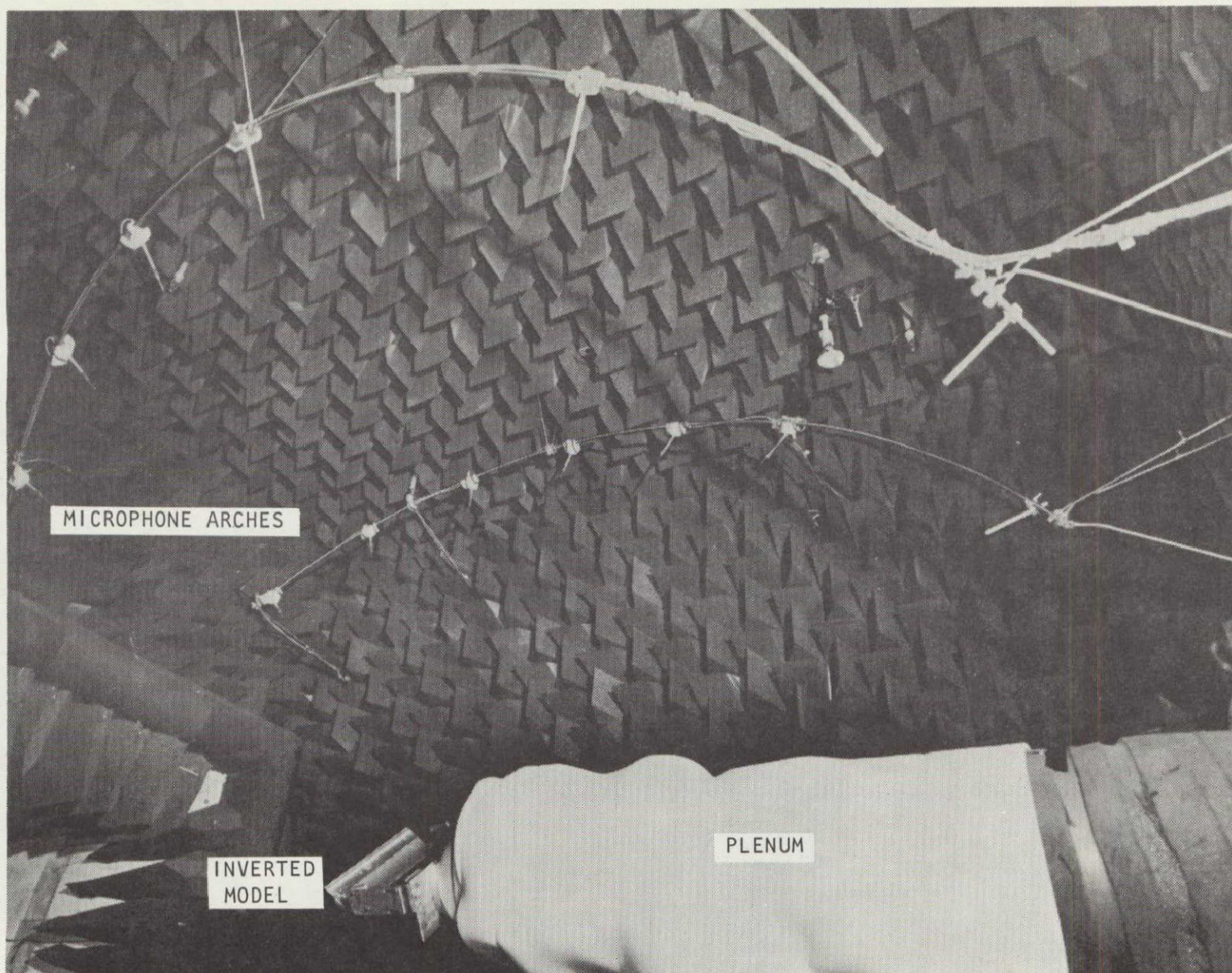


FIGURE 2-1. ANECHOIC ROOM

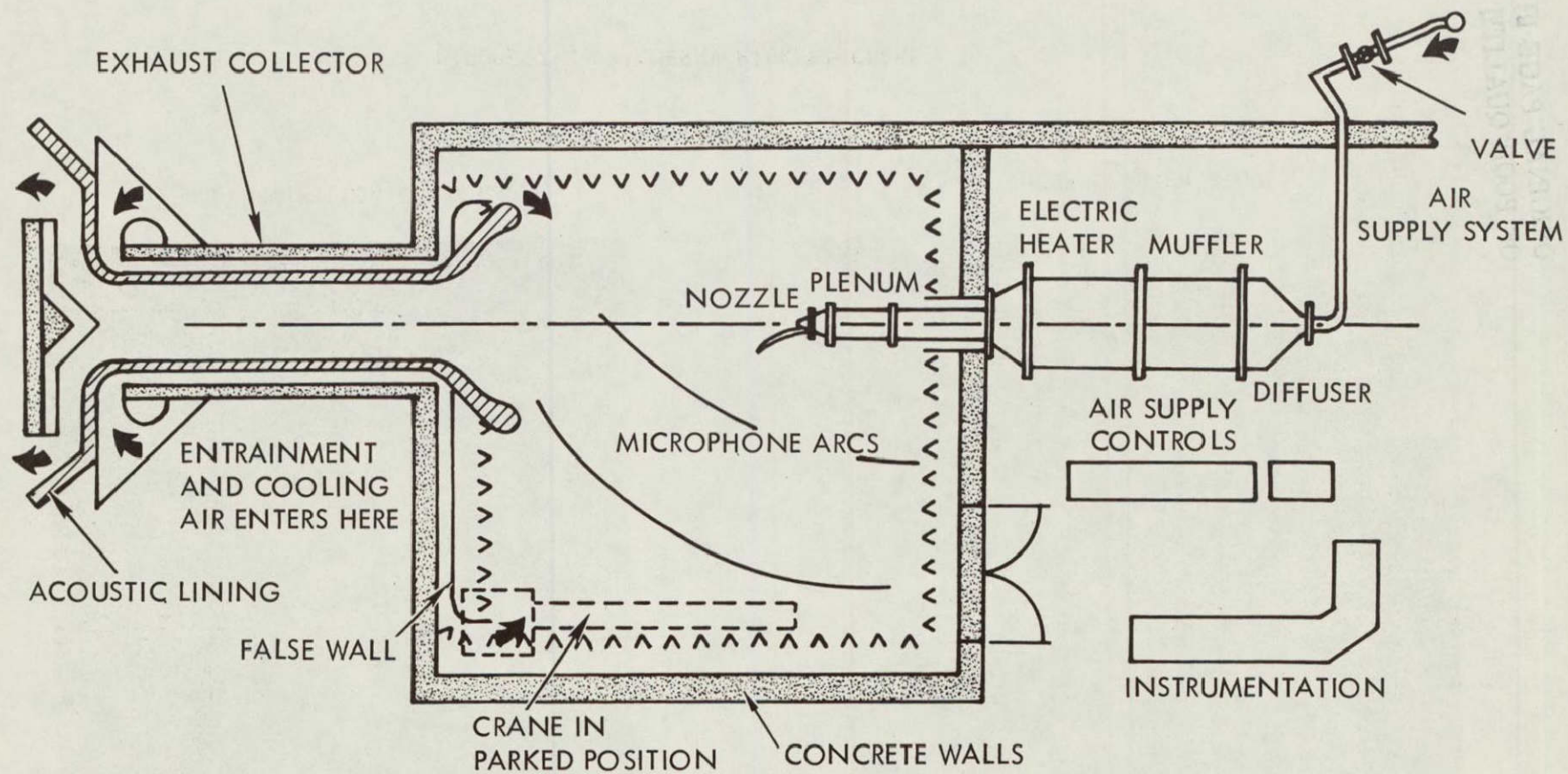
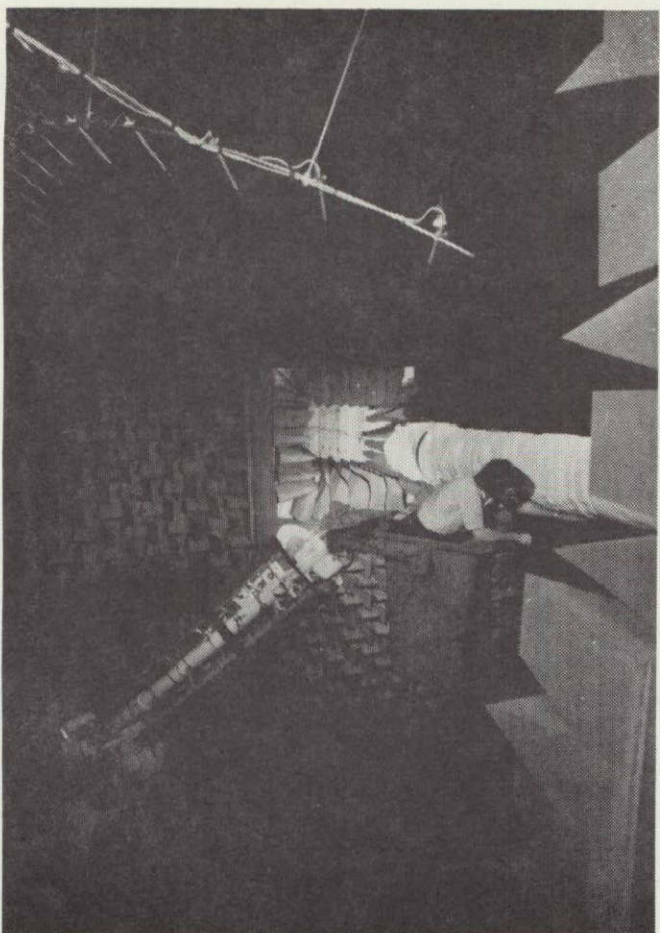
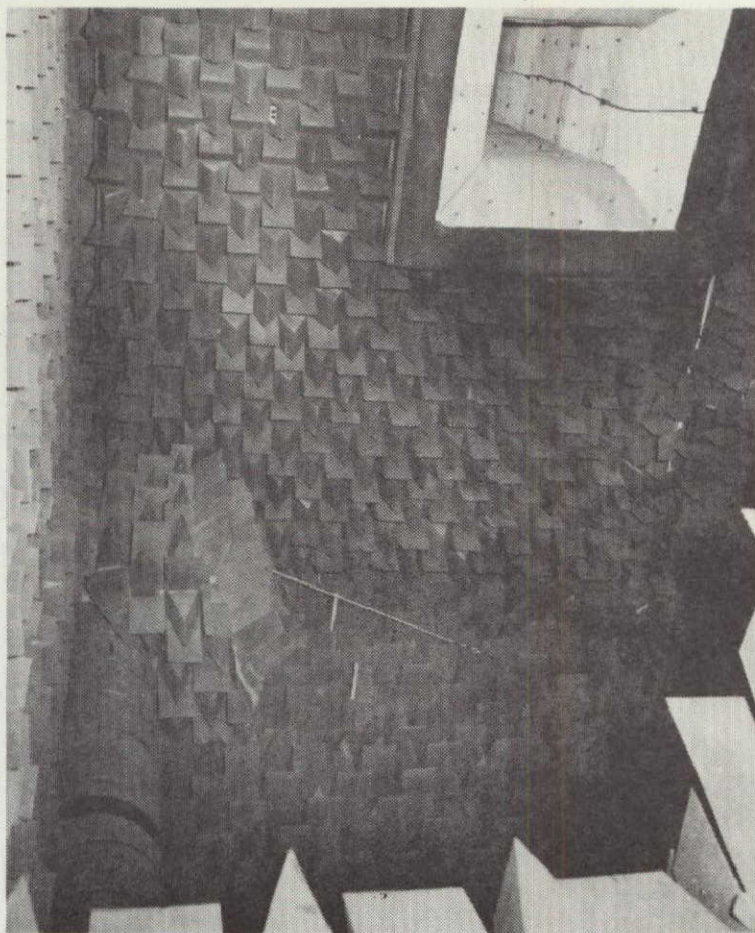


FIGURE 2-2. ANECHOIC ROOM SCHEMATIC



a) CHERRY PICKER OPERABLE



b) CHERRY PICKER STOWED

FIGURE 2-3. 'CHERRY PICKER' CRANE

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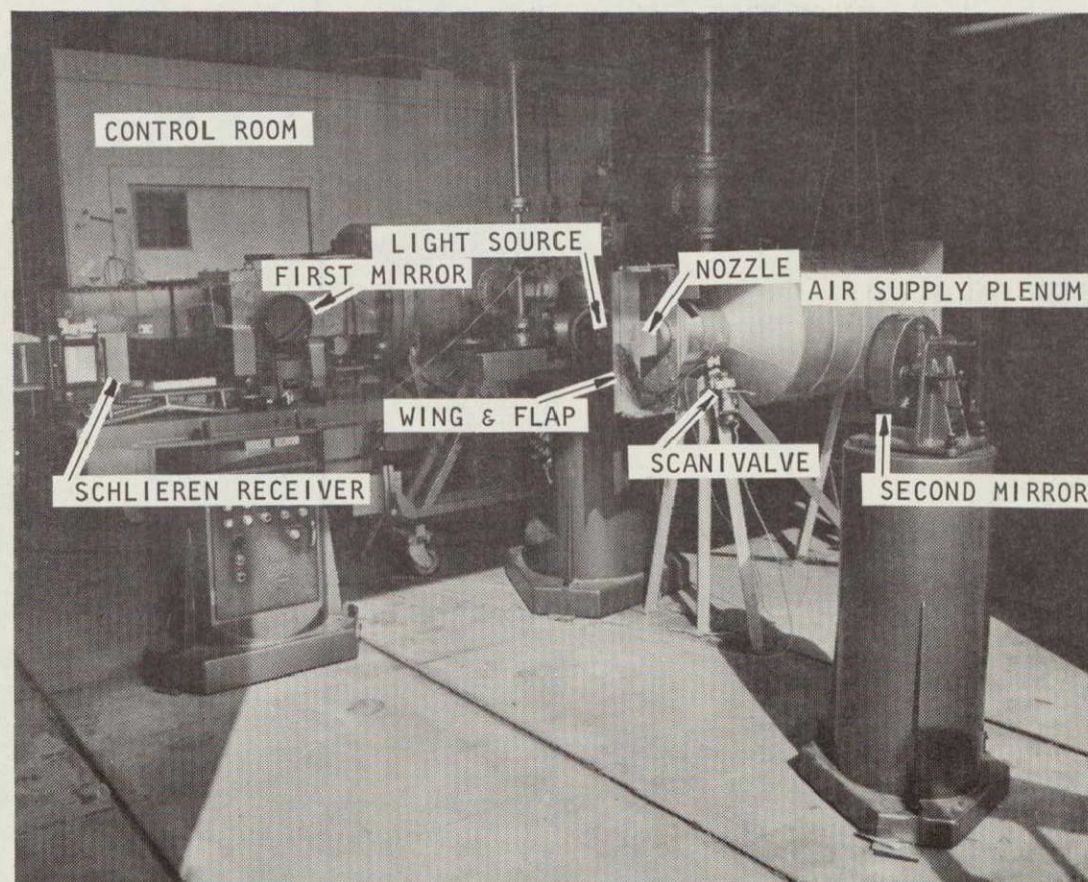


FIGURE 2-4. AEROACOUSTIC FLOW FACILITY

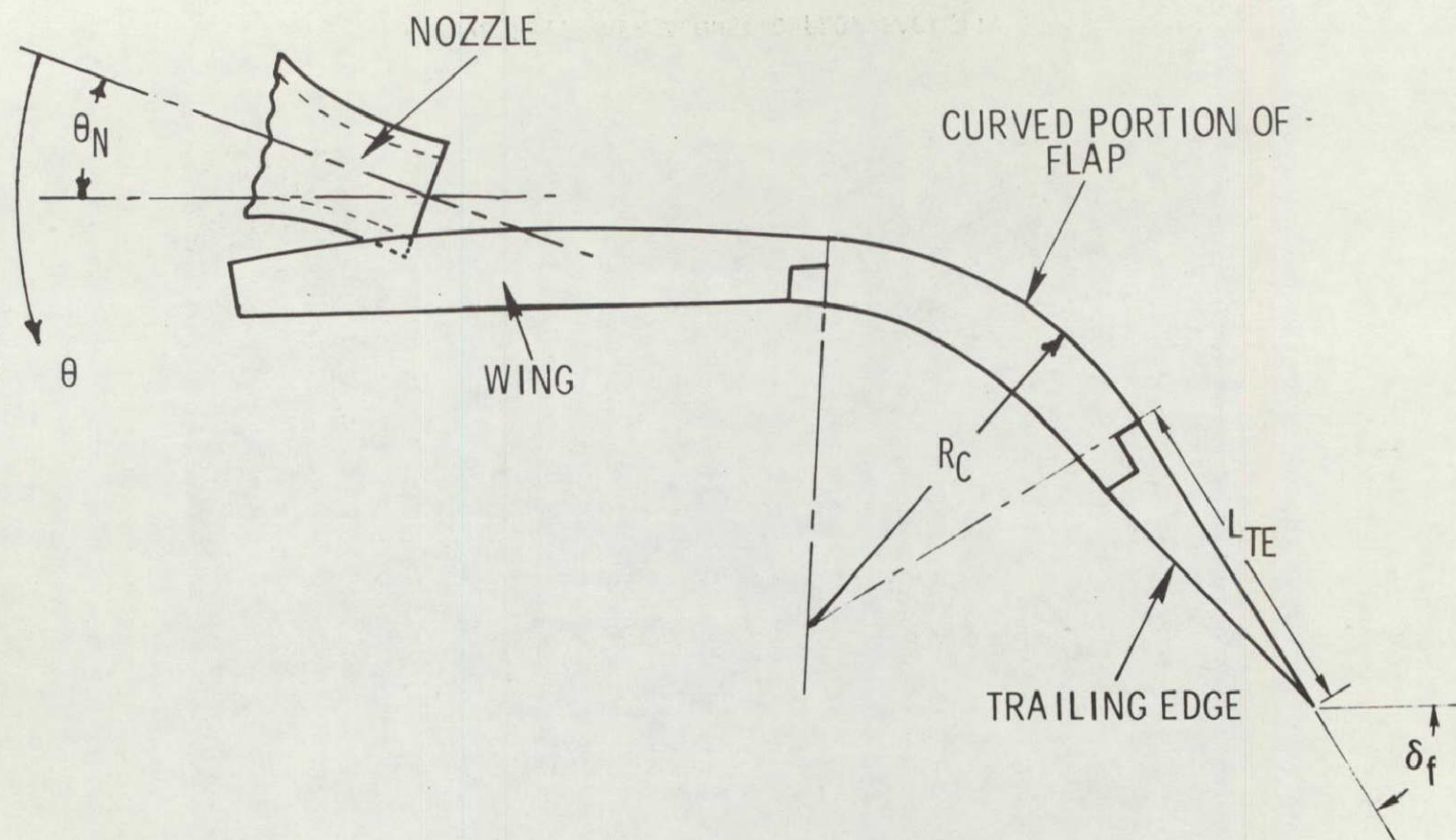
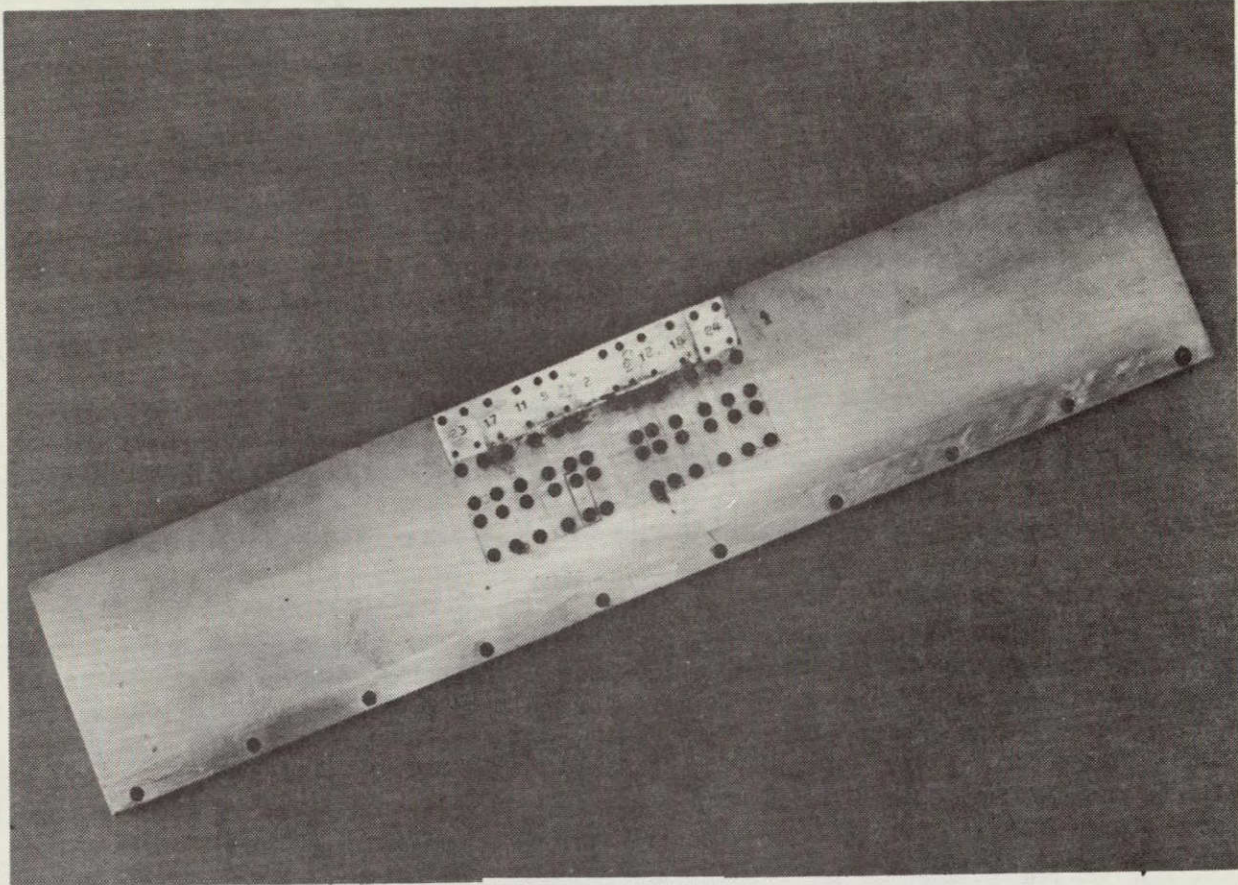
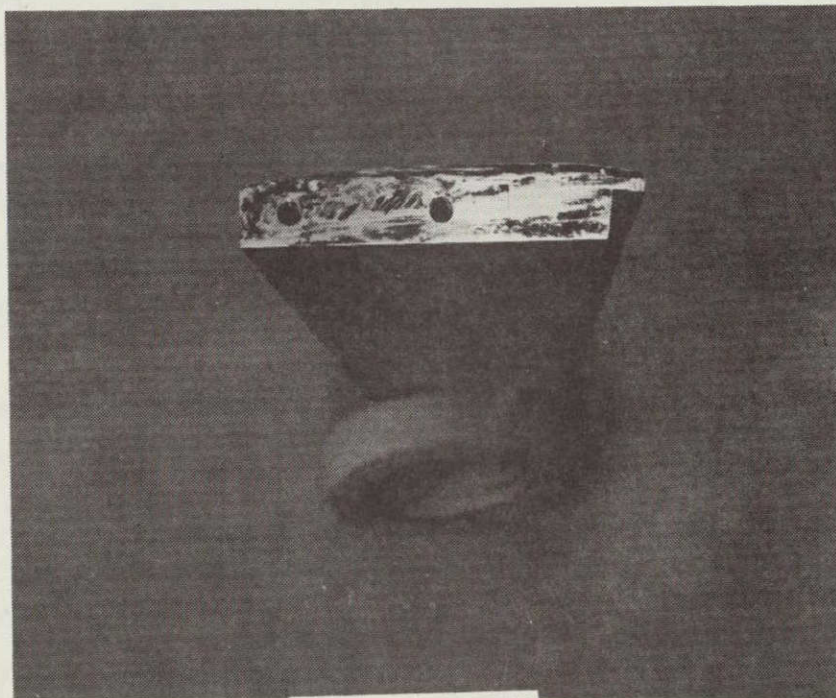


FIGURE 2-5. SMALL SCALE STATIC MODEL SCHEMATIC

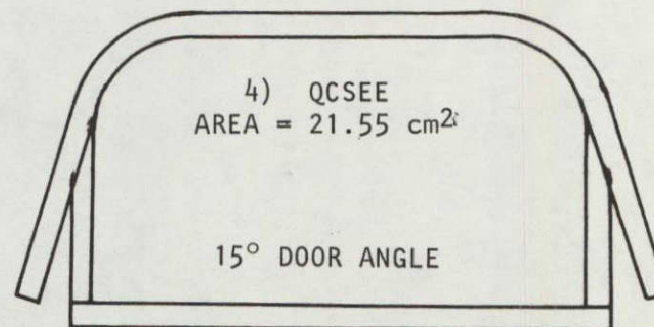
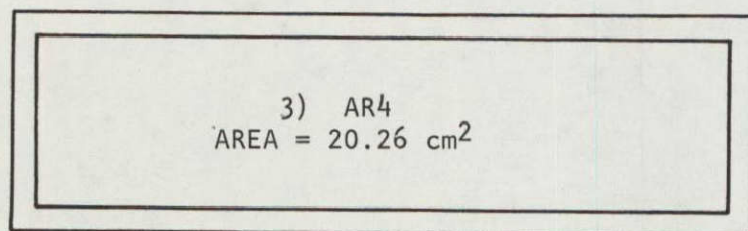
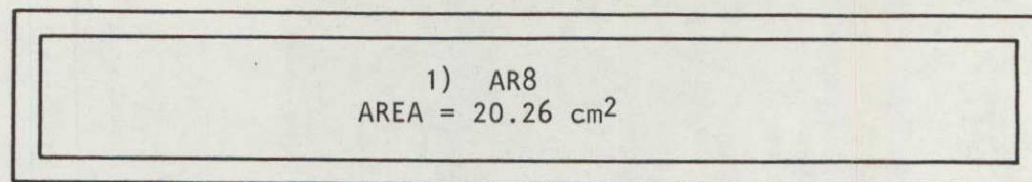
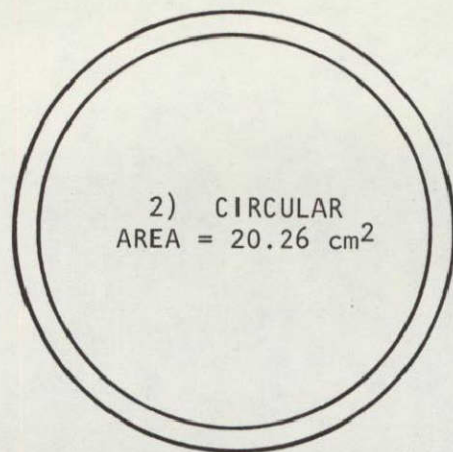


(a) PLAN VIEW



(b) SIDE VIEW

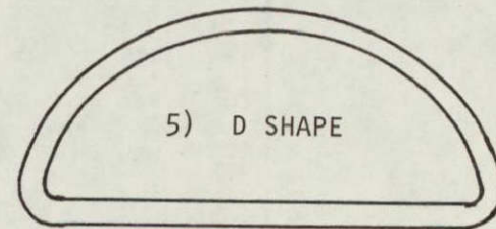
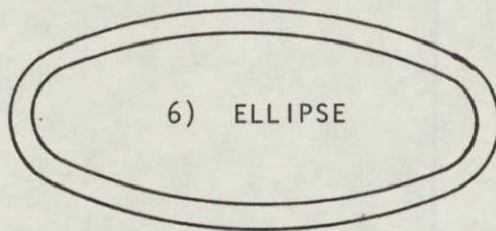
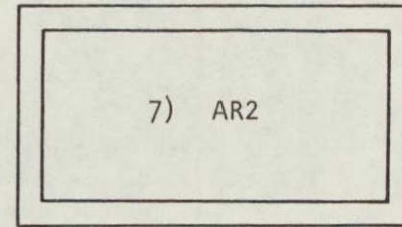
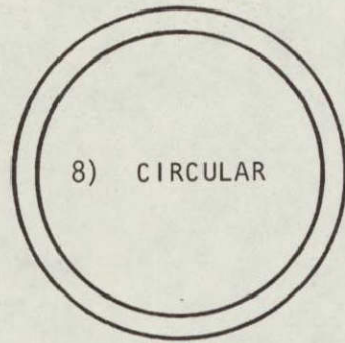
FIGURE 2-6. SMALL SCALE STATIC WING



(a) LARGE AREA NOZZLES

FIGURE 2-7. NOZZLE EXIT SHAPES

ALL AREAS = 10.13 cm²



(b) SMALL AREA NOZZLES

FIGURE 2-7. (CONCLUDED)

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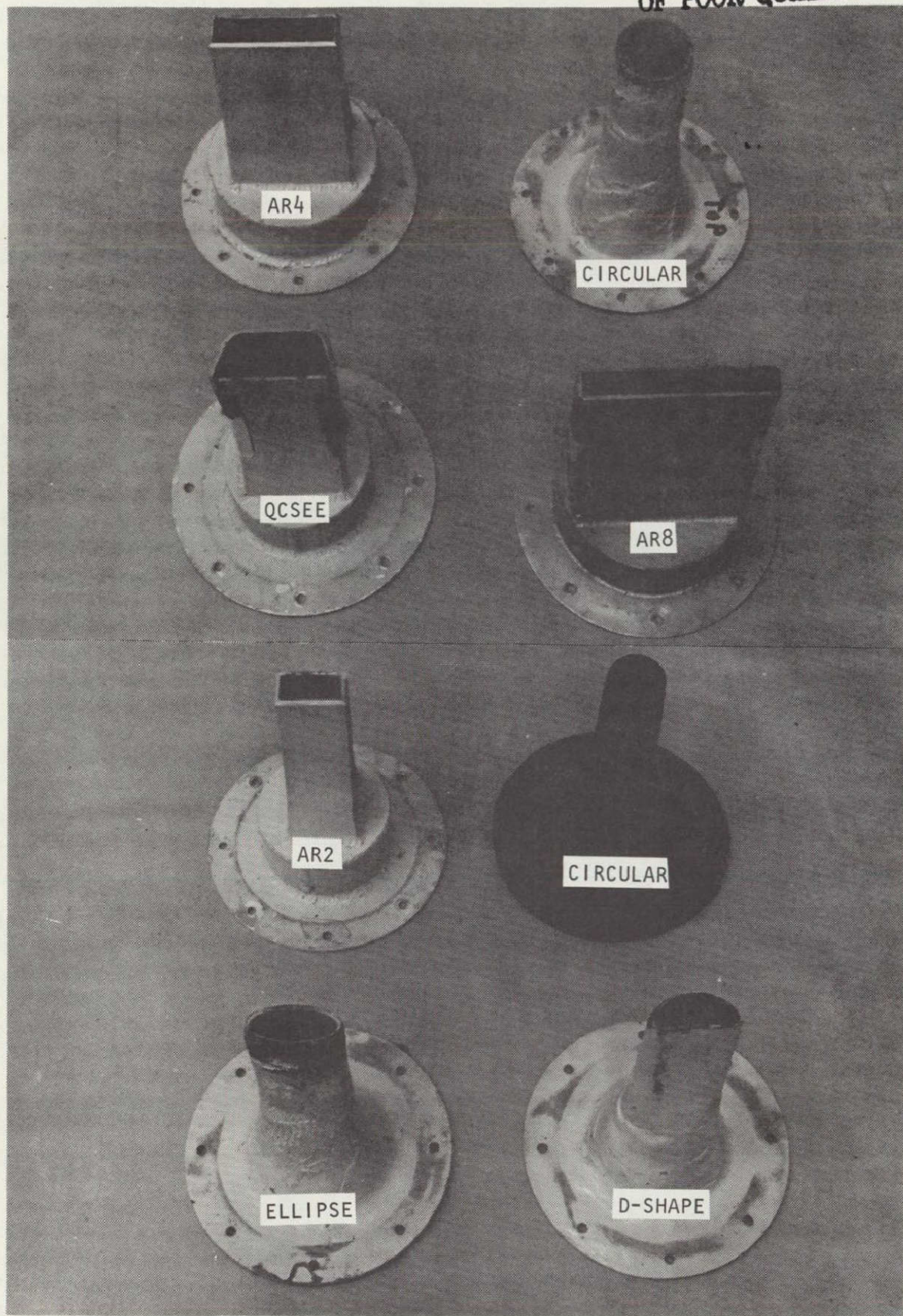
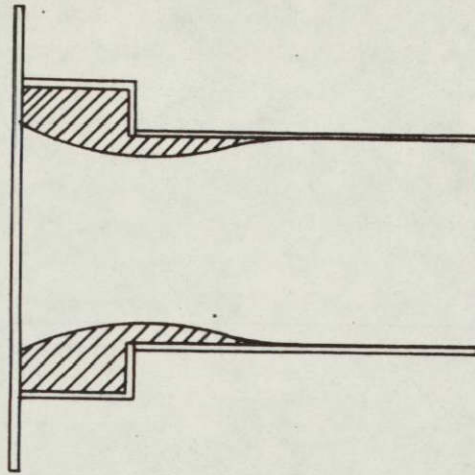
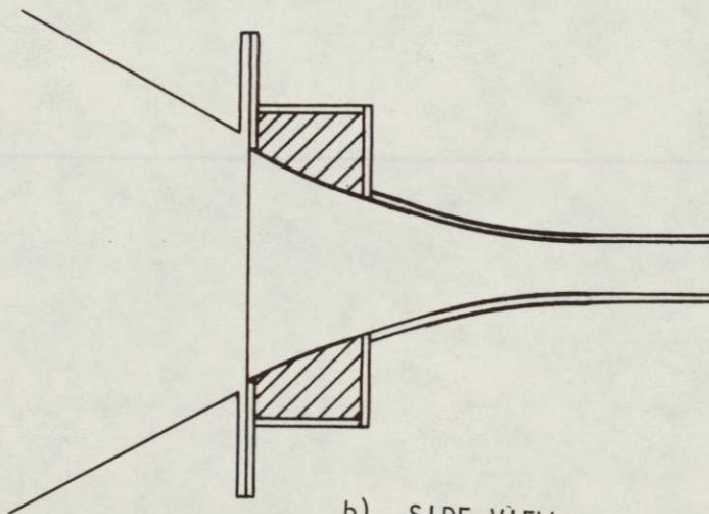


FIGURE 2-8. SMALL SCALE NOZZLES

AR 4 NOZZLE

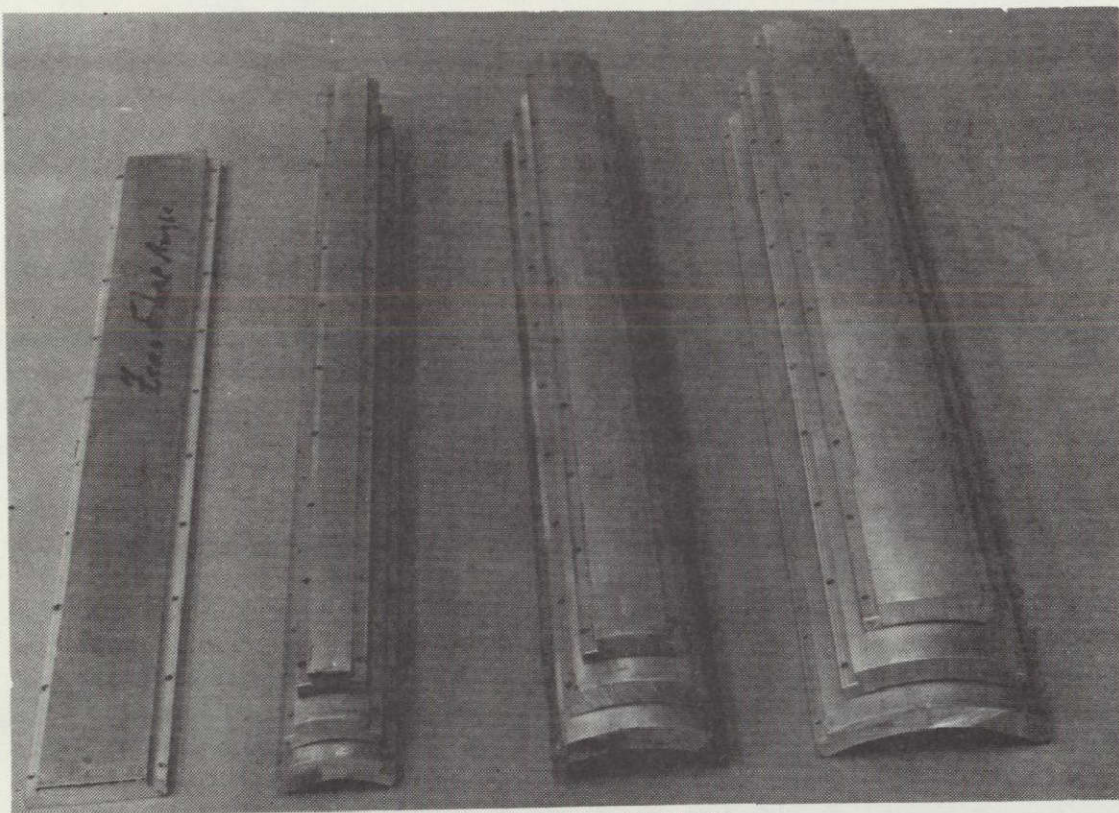


a) PLANVIEW

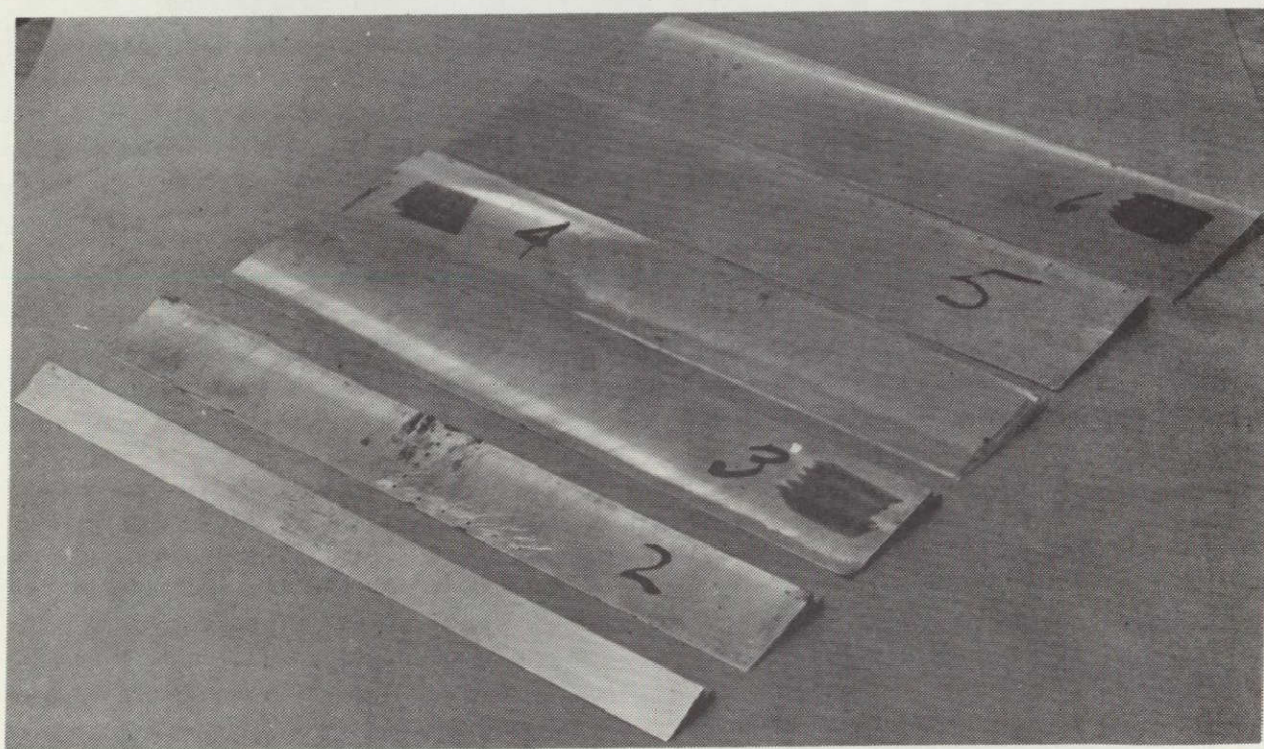


b) SIDE VIEW

FIGURE 2-9. TYPICAL INTERNAL PROFILE FOR SMALL SCALE NOZZLES

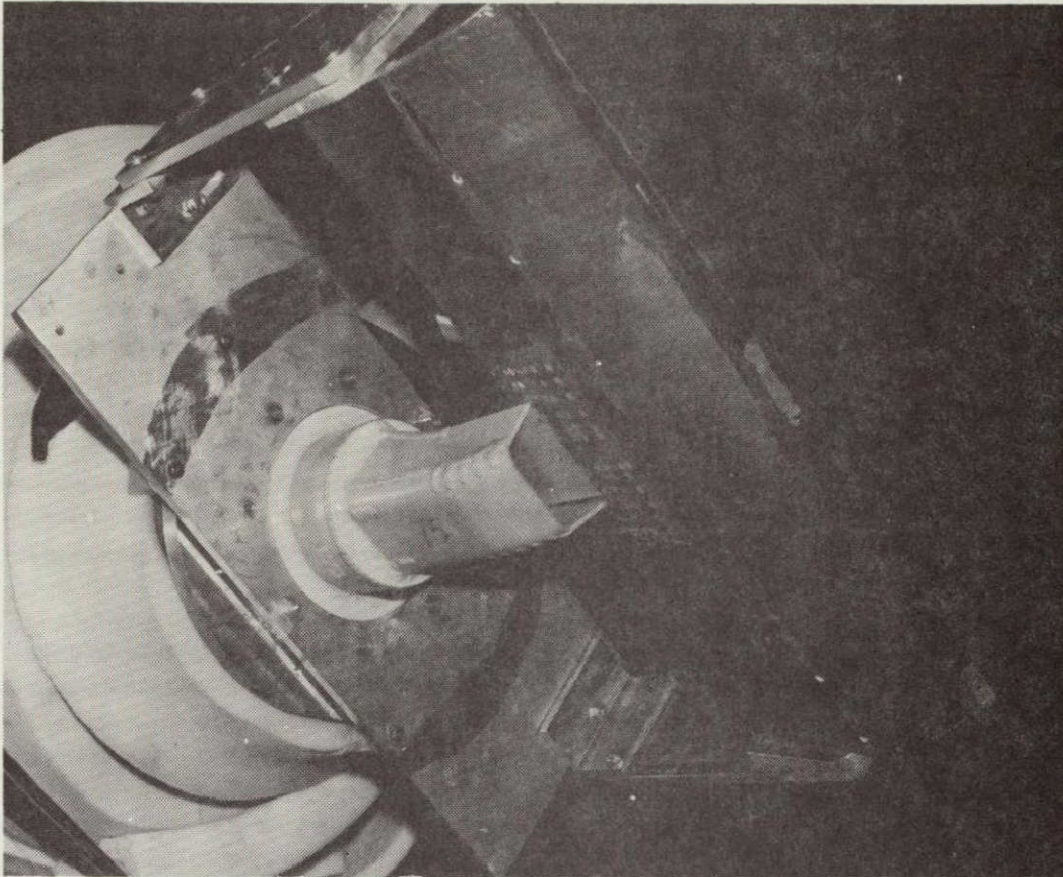


a) FLAP CURVED PORTIONS

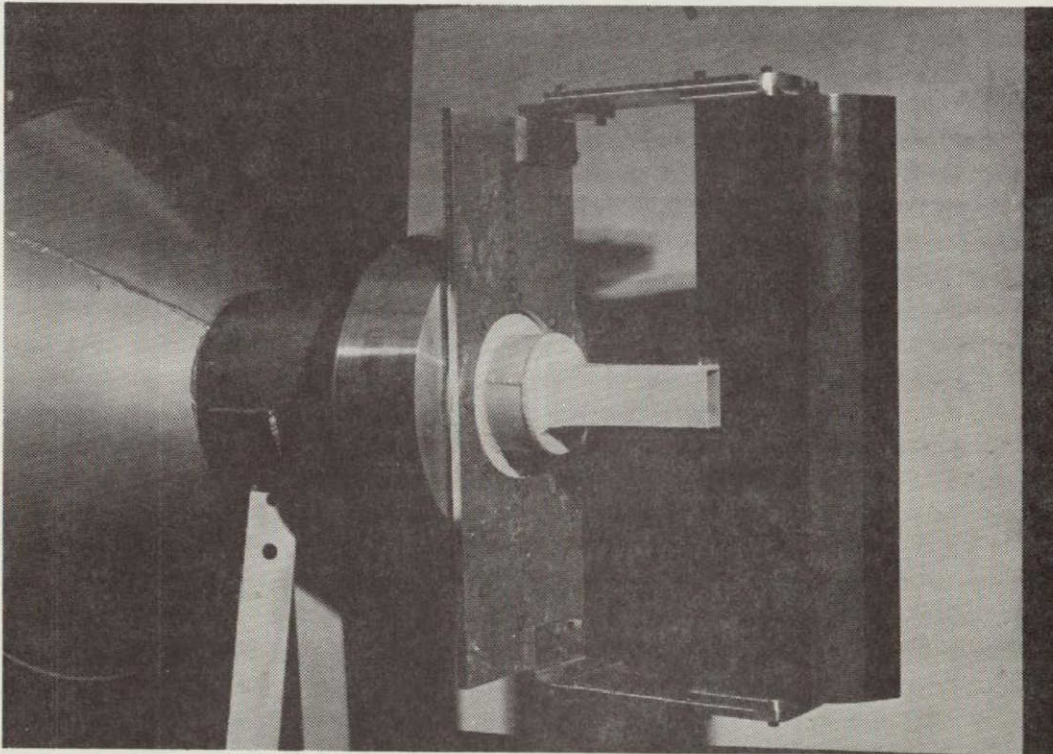


b) FLAP TRAILING-EDGES

FIGURE 2-10. SMALL SCALE MODEL PARTS



a) ANECHOIC ROOM



b) AEROACOUSTIC FLOW FACILITY

FIGURE 2-11. WING MOUNTING BRACKETS

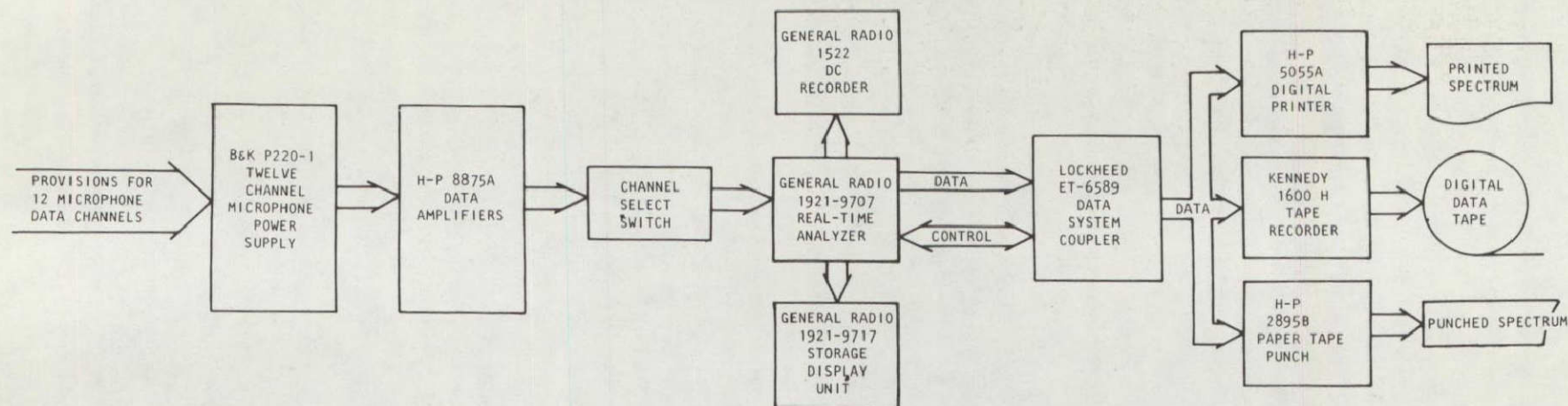


FIGURE 2-12. ACOUSTIC DATA ACQUISITION SYSTEM

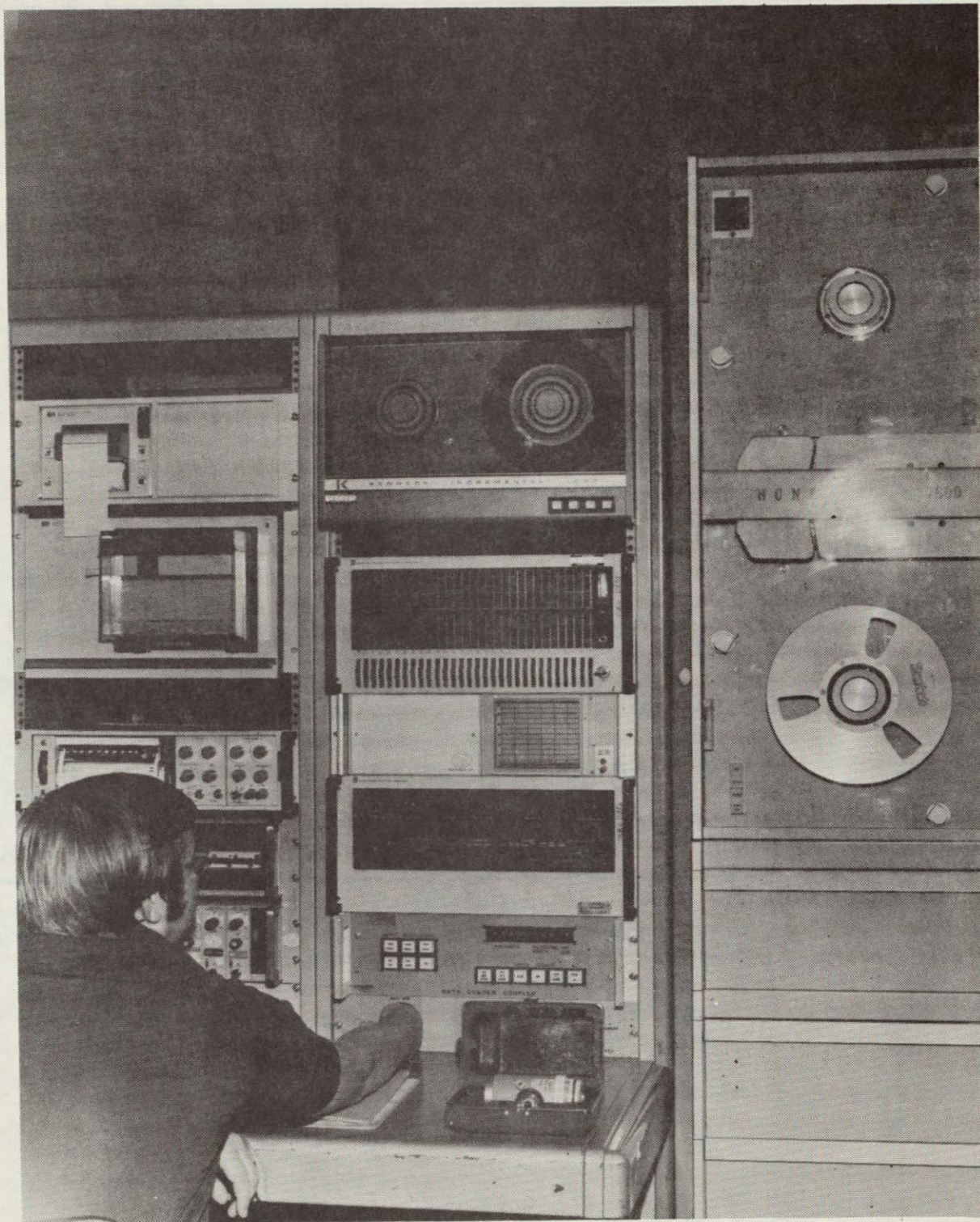


FIGURE 2-13. ACOUSTIC DATA ACQUISITION EQUIPMENT

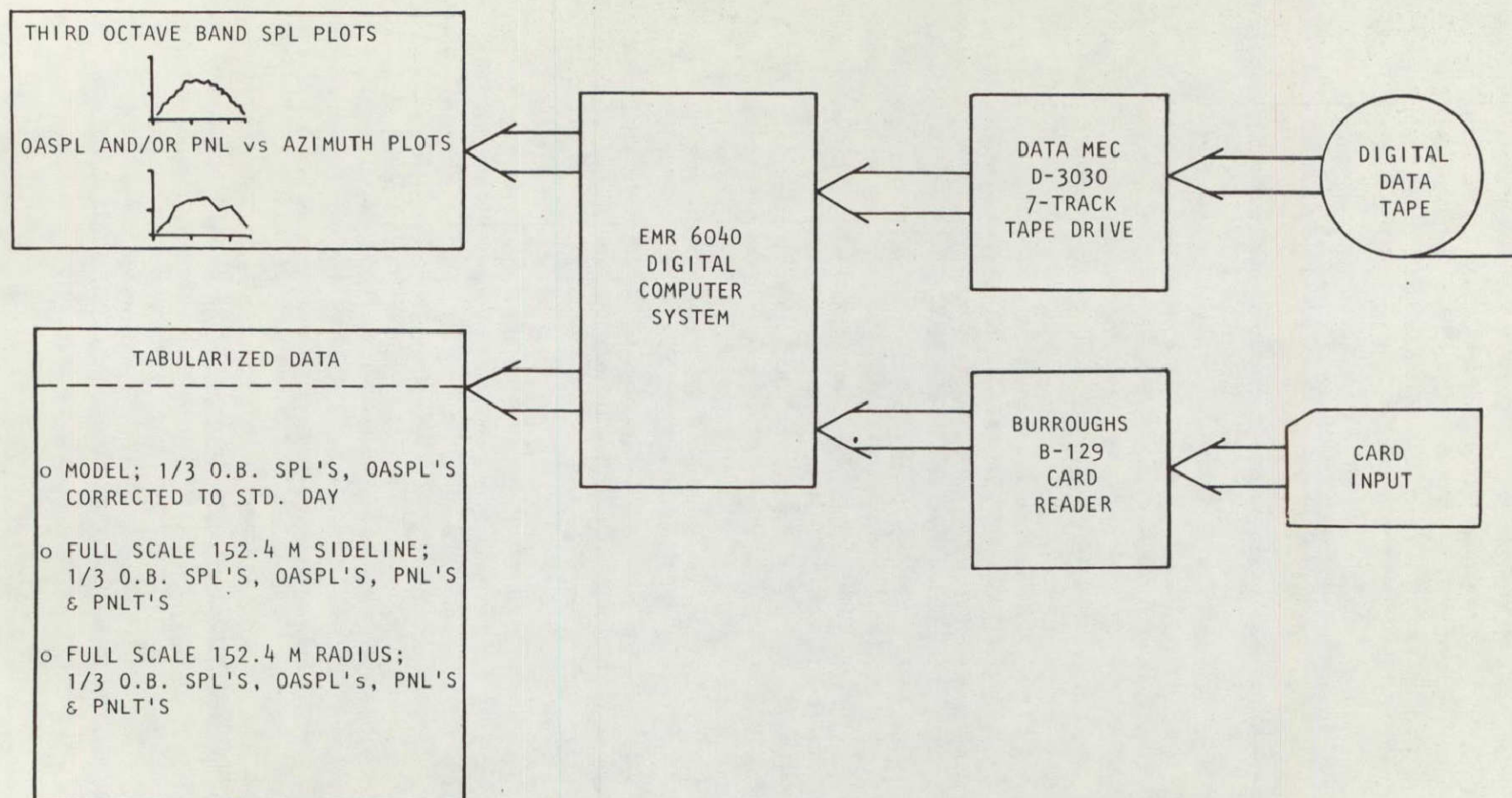


FIGURE 2-14. ACOUSTIC MASS DATA REDUCTION SYSTEM

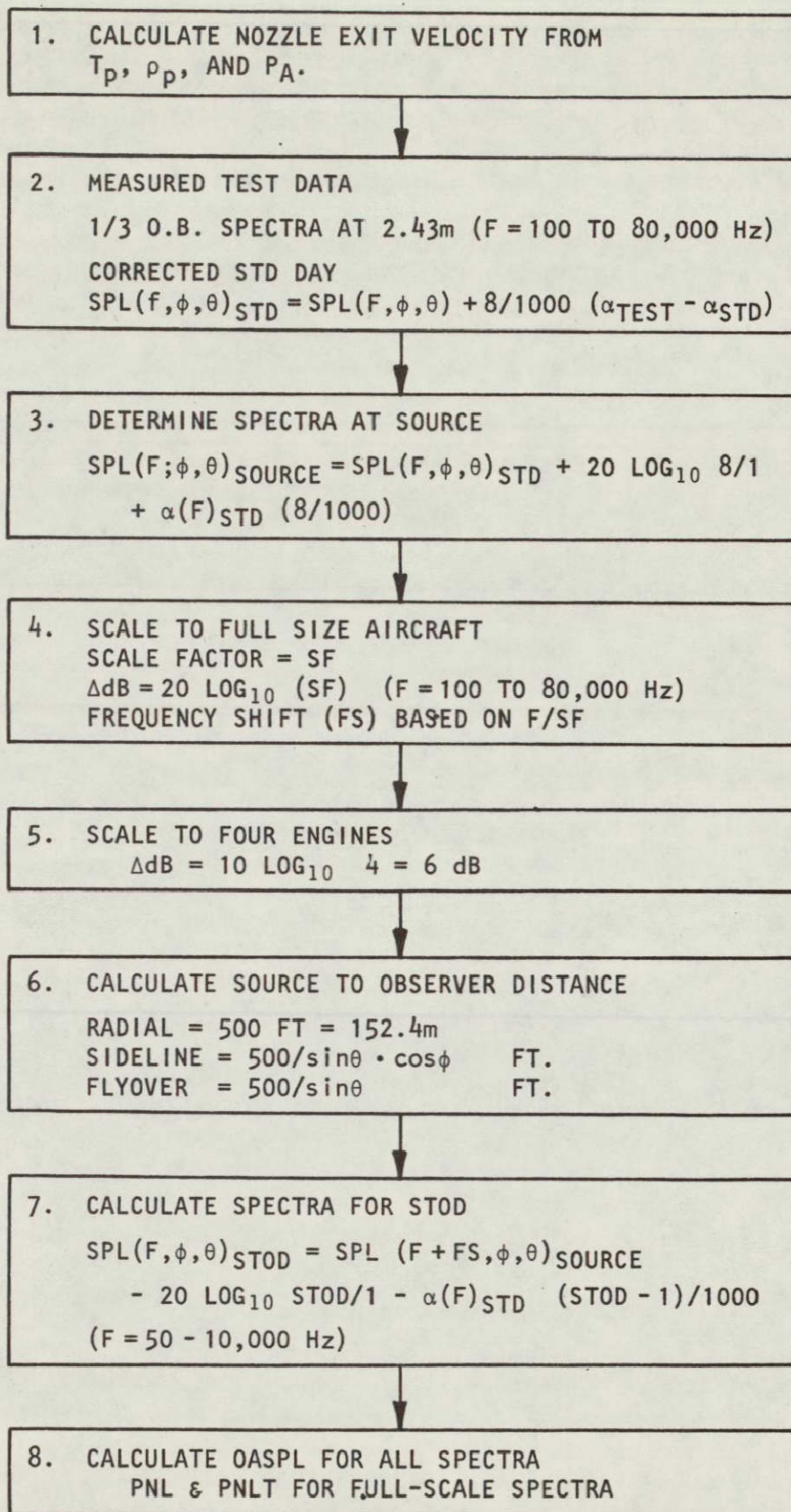


FIGURE 2-15. ACOUSTIC DATA REDUCTION PROGRAM FLOW CHART

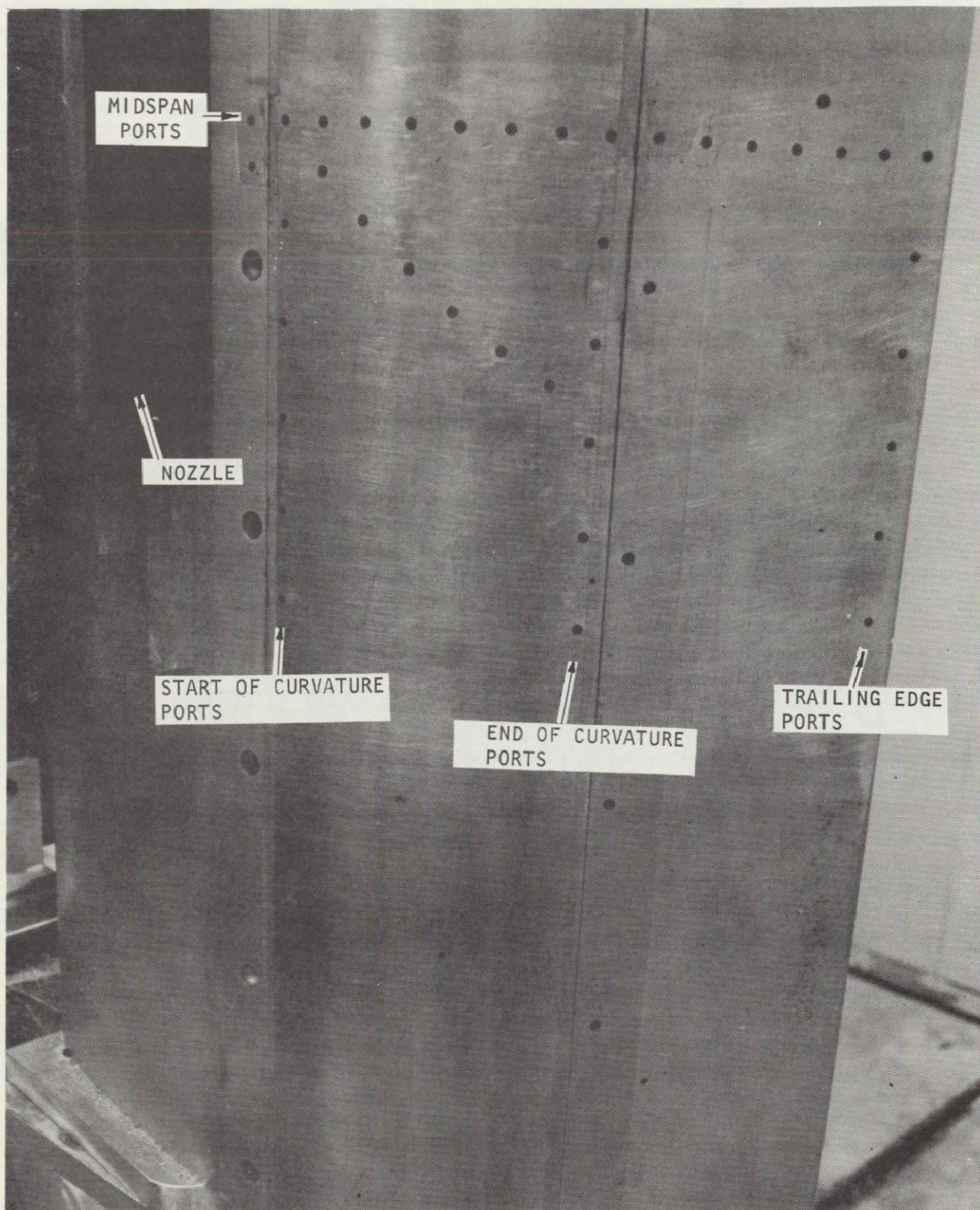


FIGURE 2-16. STATIC PRESSURE PORT LAYOUT

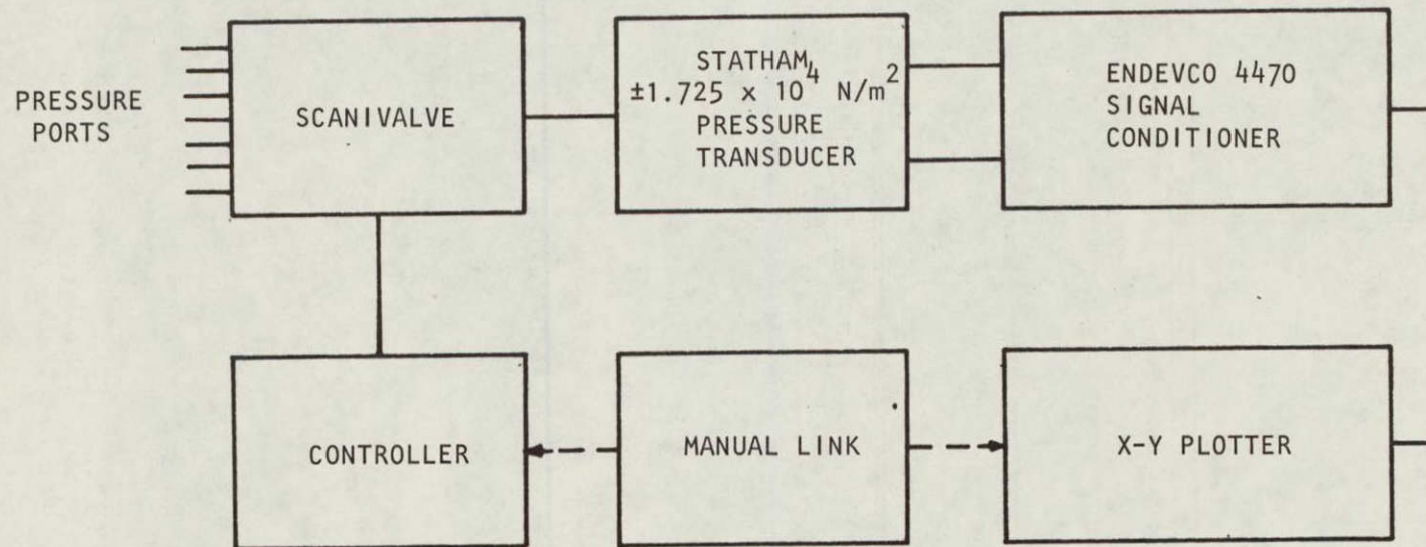


FIGURE 2-17. SURFACE STATIC PRESSURE INSTRUMENTATION

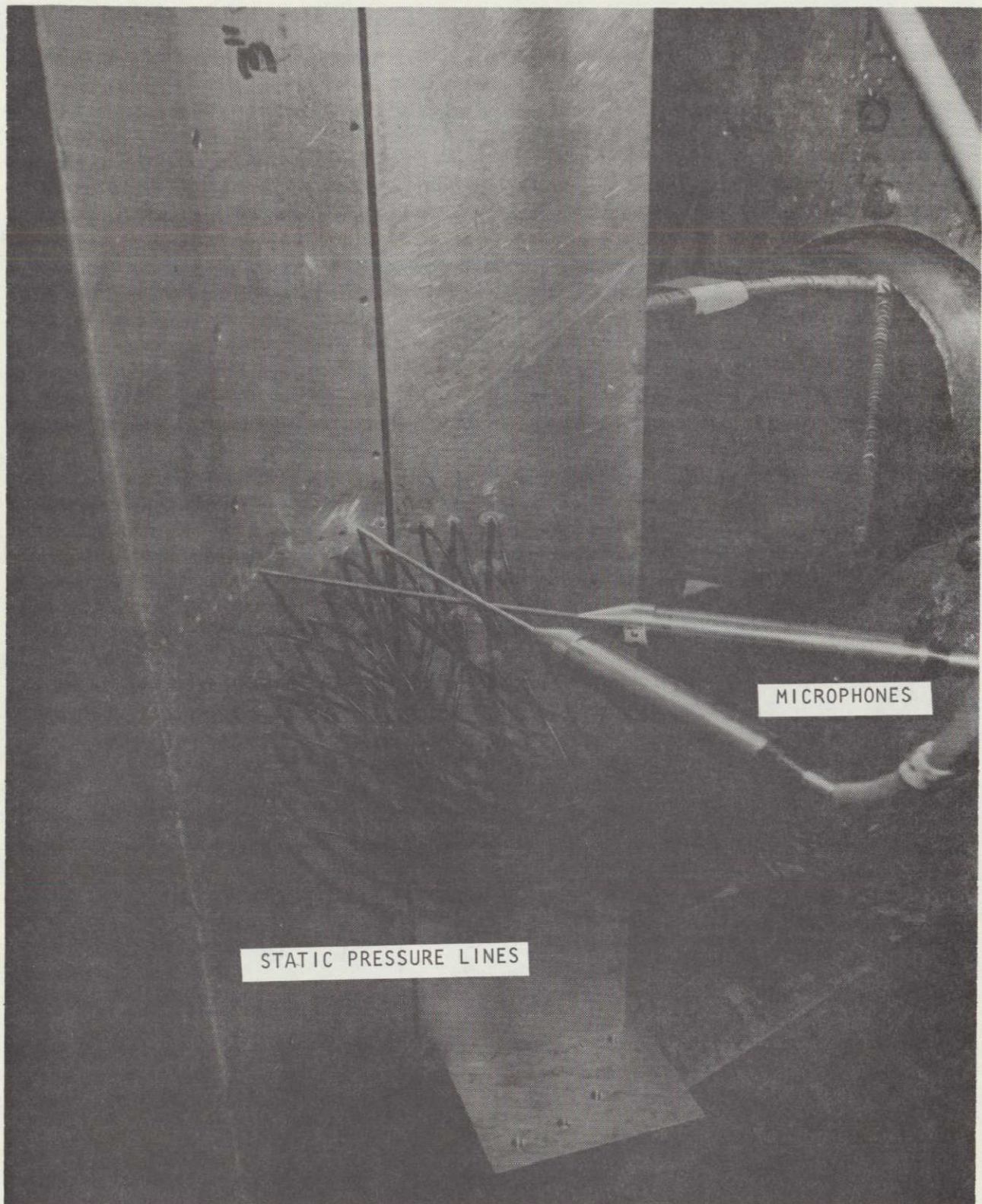


FIGURE 2-18. PROBE MICROPHONE INSTALLATION

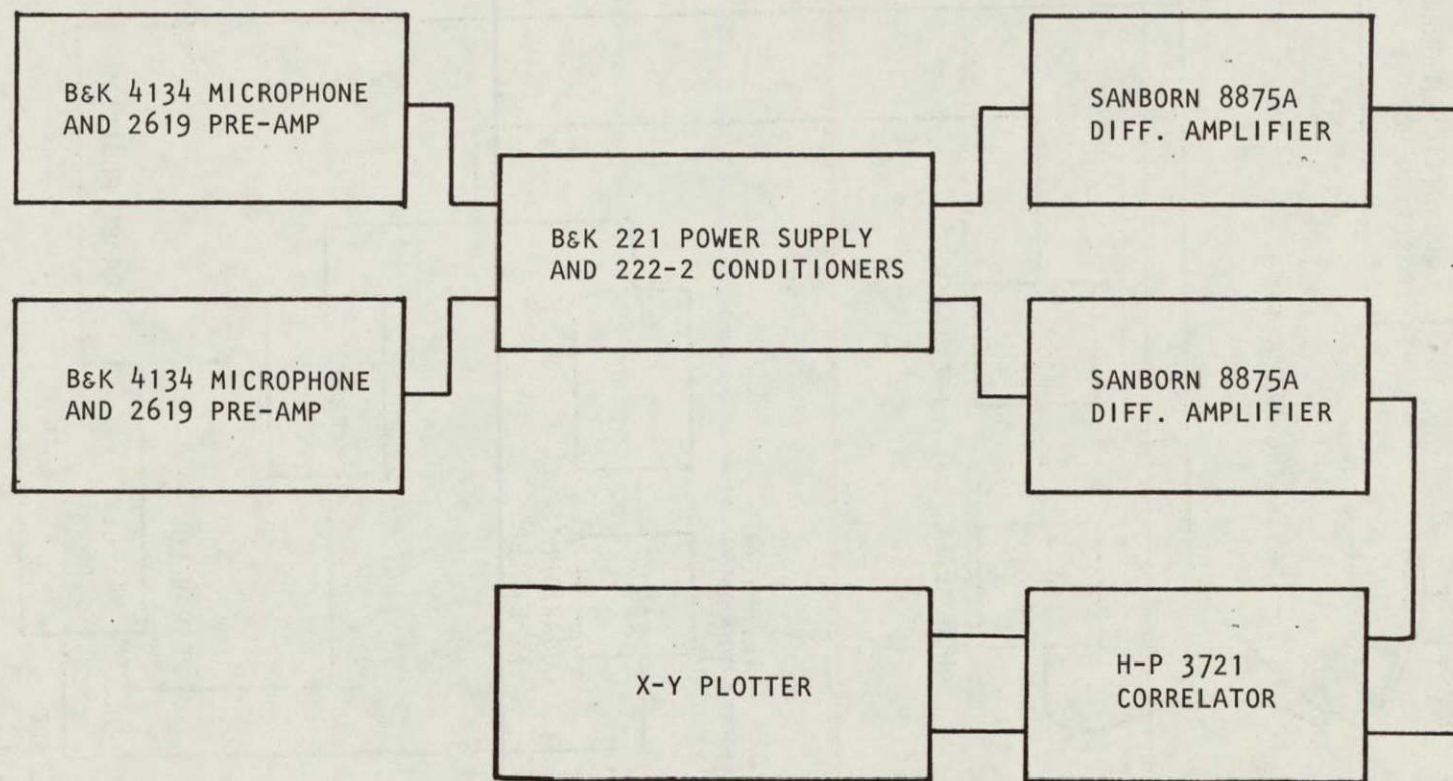


FIGURE 2-19. SURFACE PRESSURE CORRELATION INSTRUMENTATION

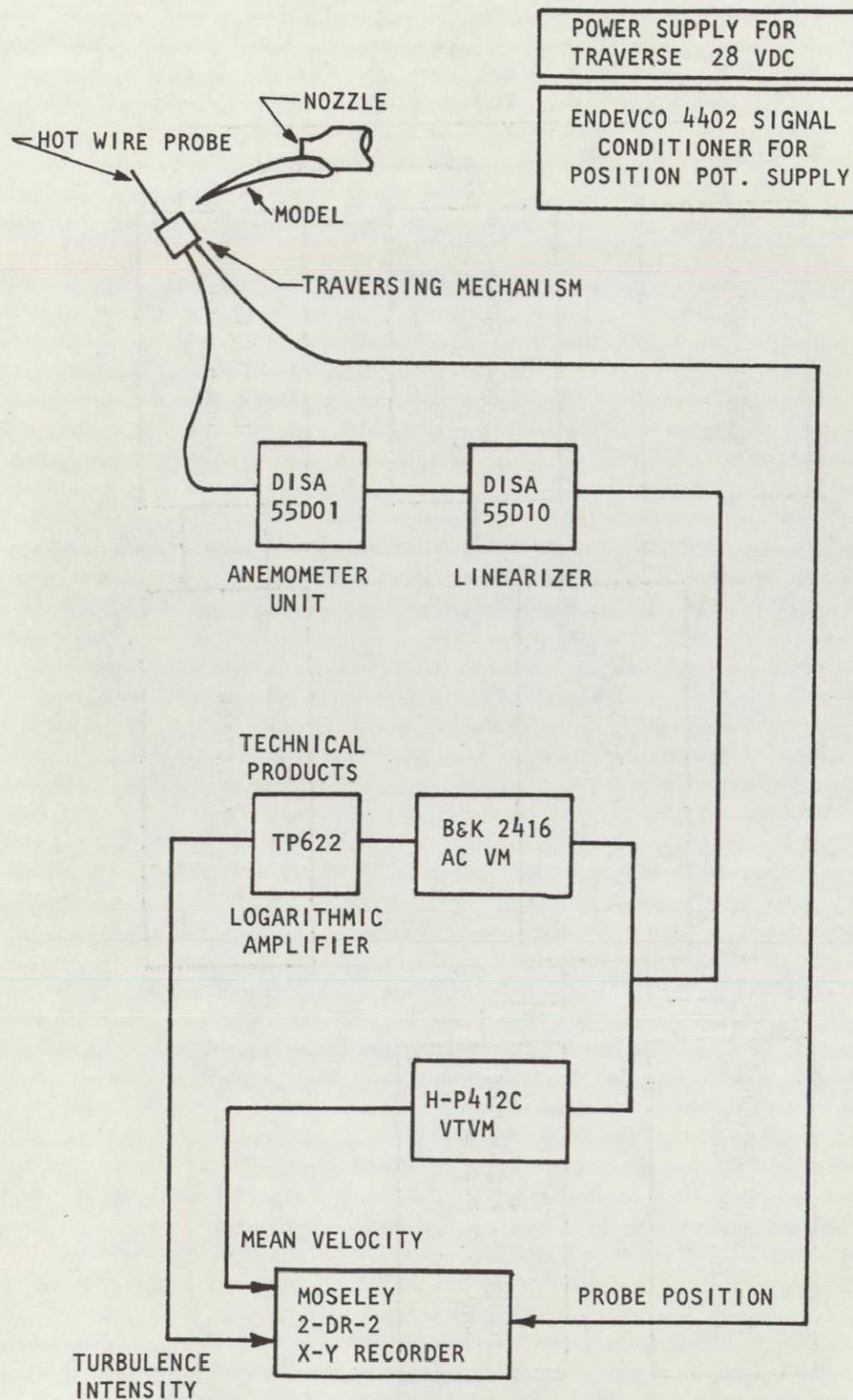


FIGURE 2-20. HOT-WIRE ANEMOMETRY INSTRUMENTATION



a) END VIEW

FIGURE 2-21. LARGE SCALE NOZZLES

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b) SIDE VIEW

FIGURE 2-21. (CONCLUDED)

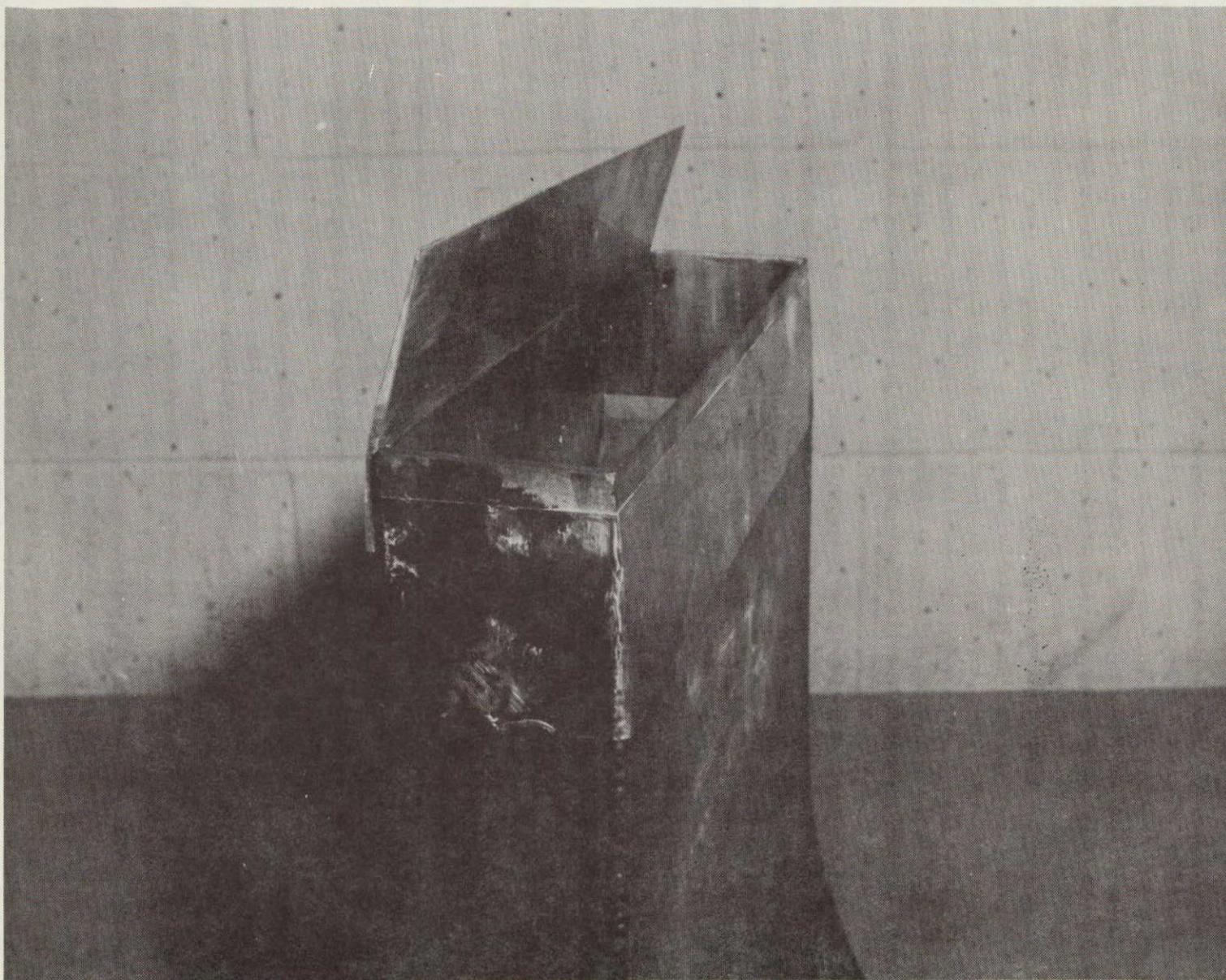


FIGURE 2-22. LARGE SCALE AR-4D NOZZLE

27 1004 2A 10010
111110 1004 10

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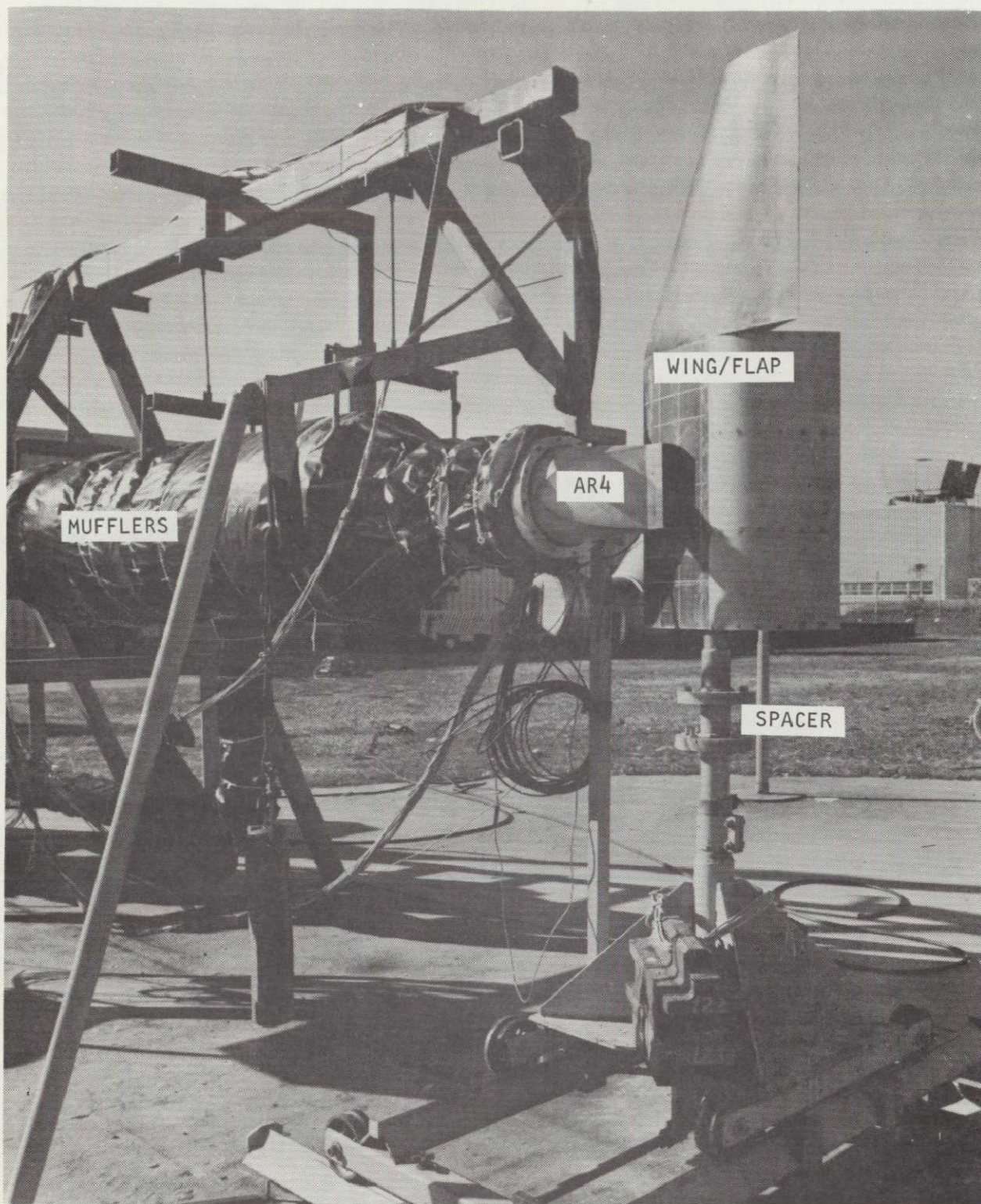
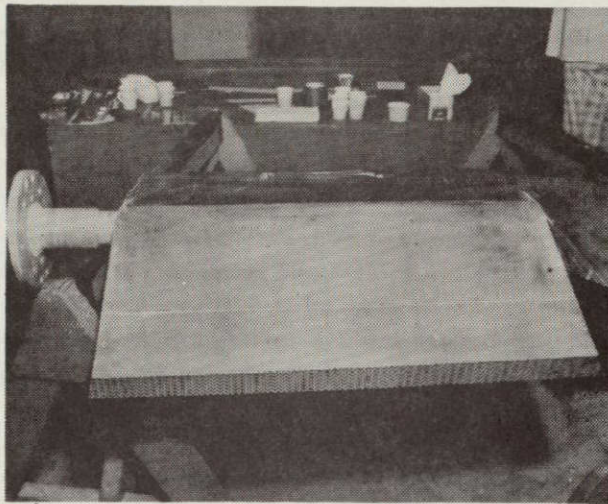
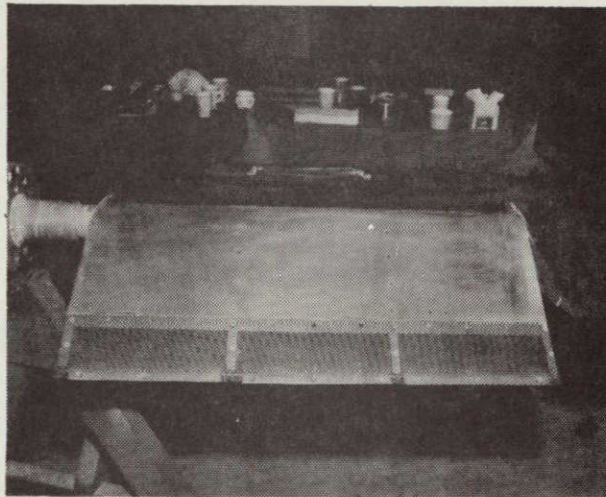


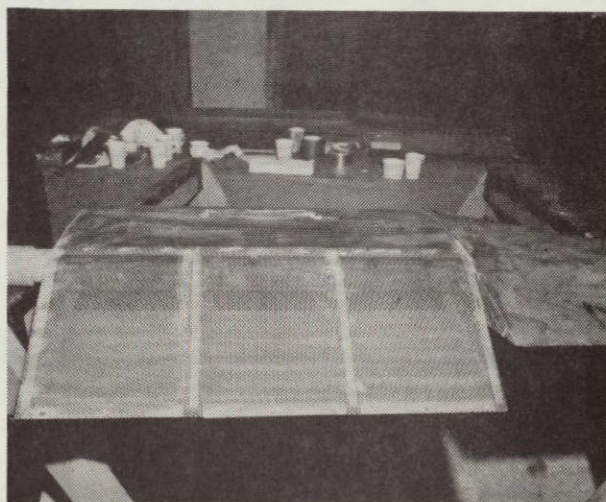
FIGURE 2-23. ACOUSTIC AND PERFORMANCE TEST RIG



a) EXTENDED TRAILING EDGE TREATMENT



b) LOWER SECTION TREATMENT



c) FULL FLAP TREATMENT

FIGURE 2-24. NOISE REDUCTION TREATMENTS

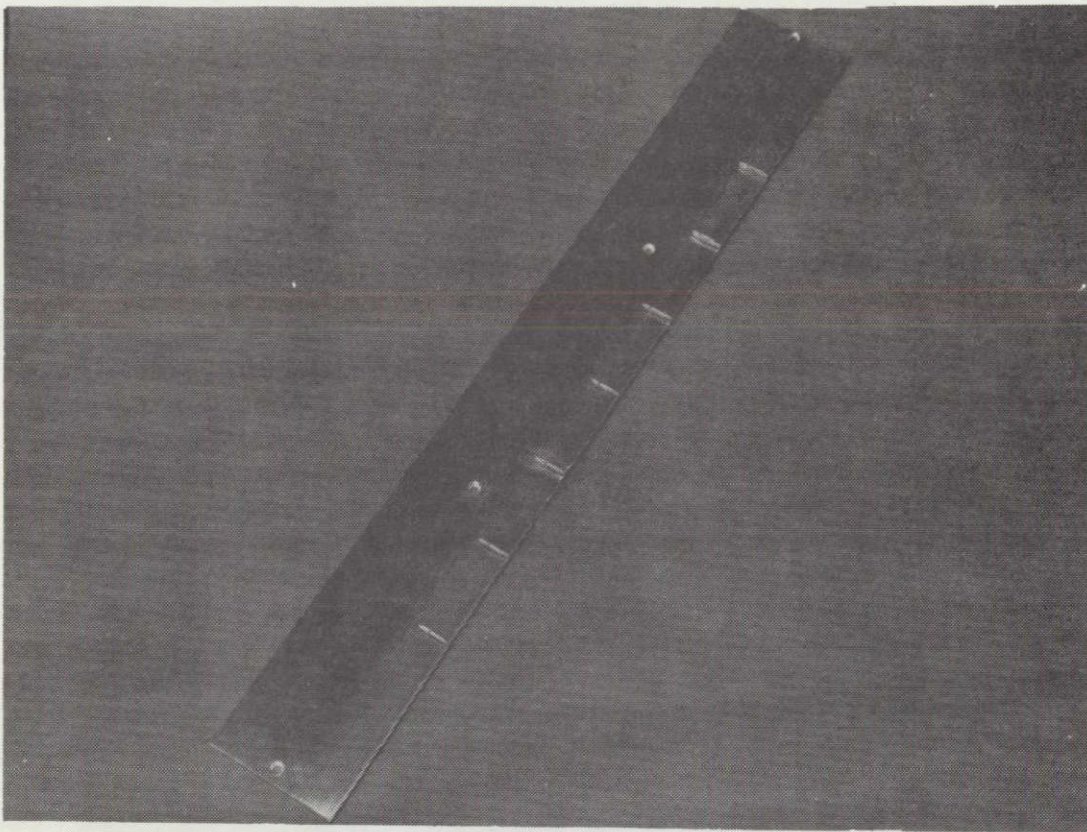


FIGURE 2-25. TRAILING EDGE SPOILERS

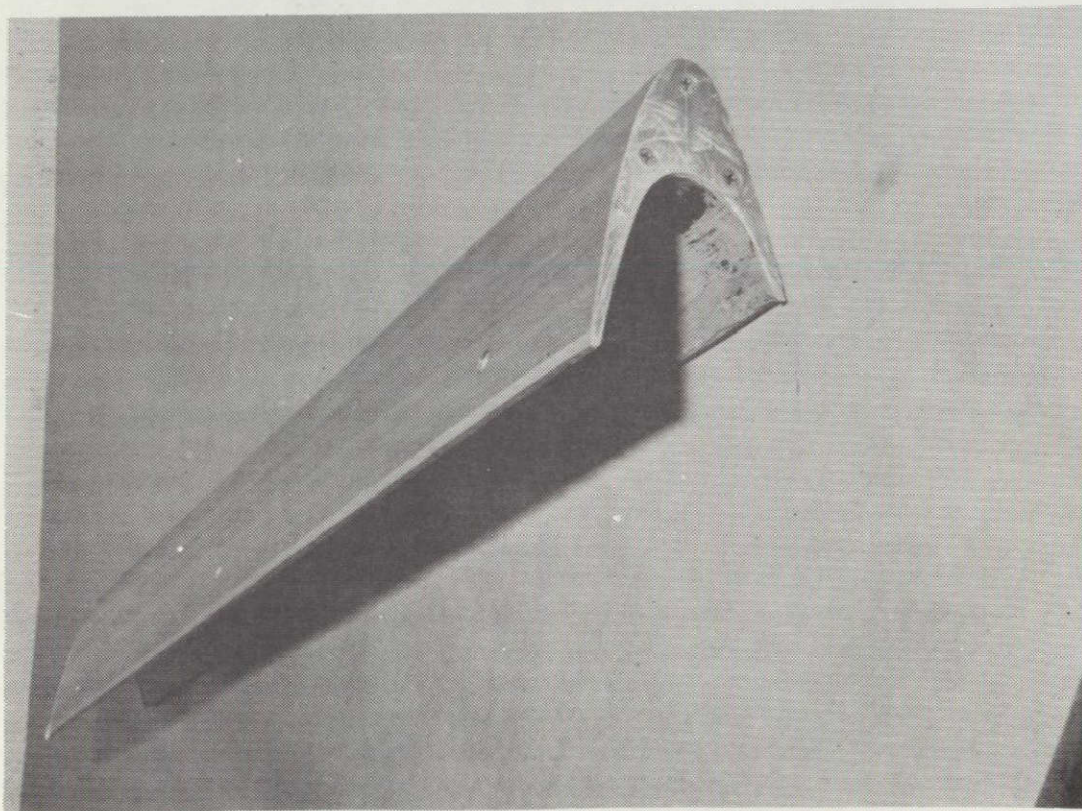


FIGURE 2-26. WING LEADING EDGE EXTENSION

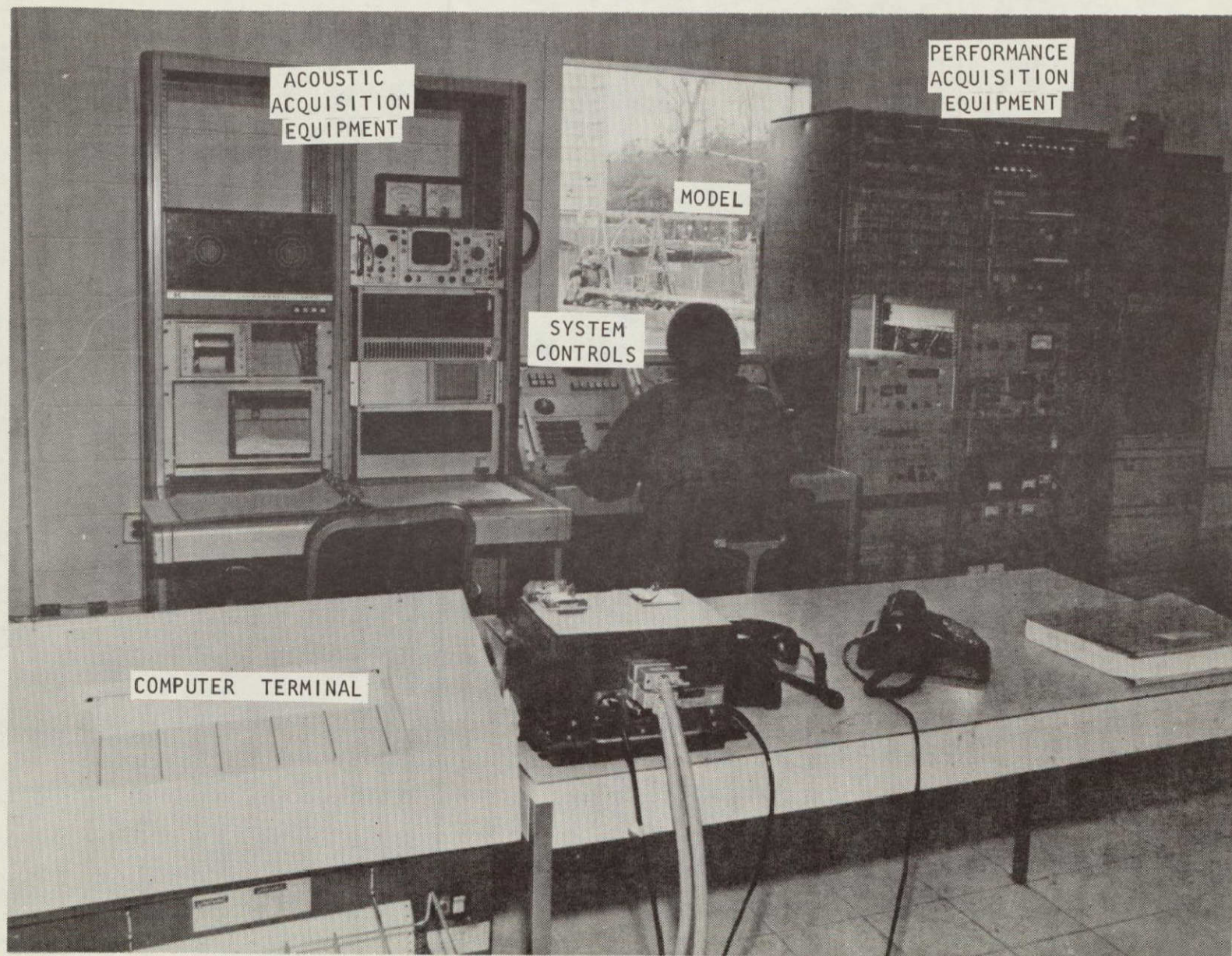


FIGURE 2-27. TEST CONTROL ROOM



FIGURE 2-28. ACOUSTIC AND PERFORMANCE TEST FACILITY

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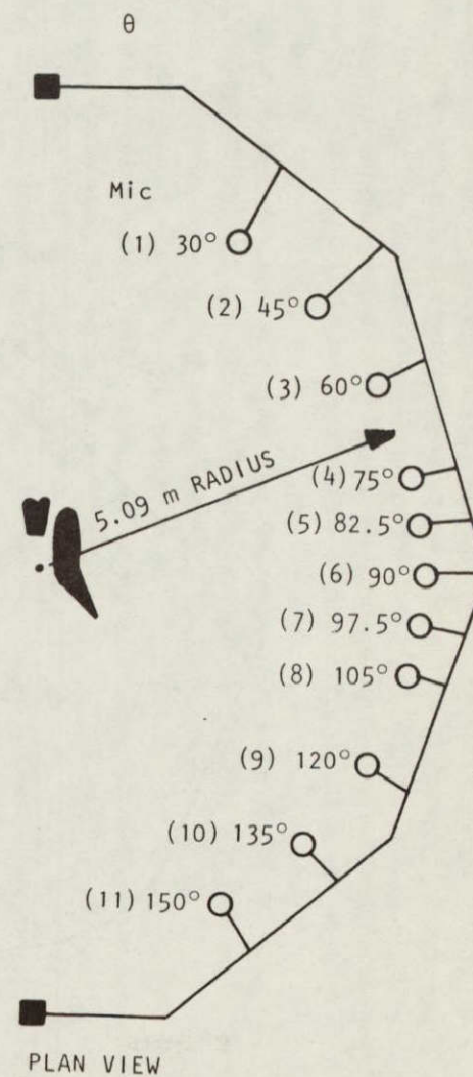
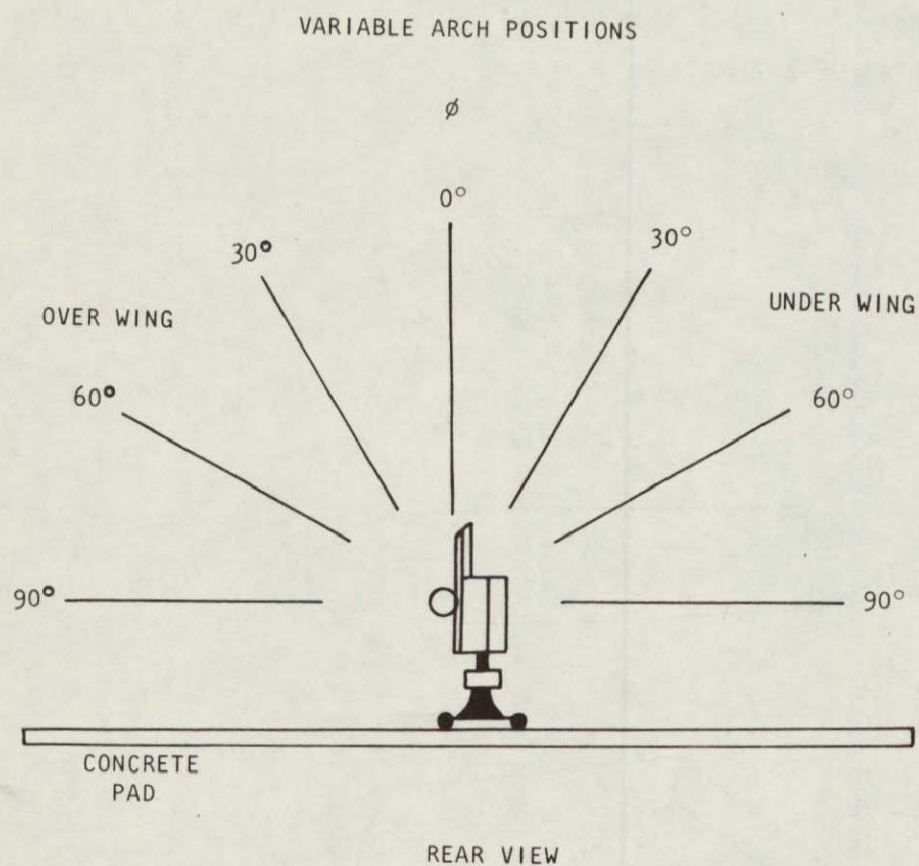


FIGURE 2-29. MICROPHONE LOCATIONS

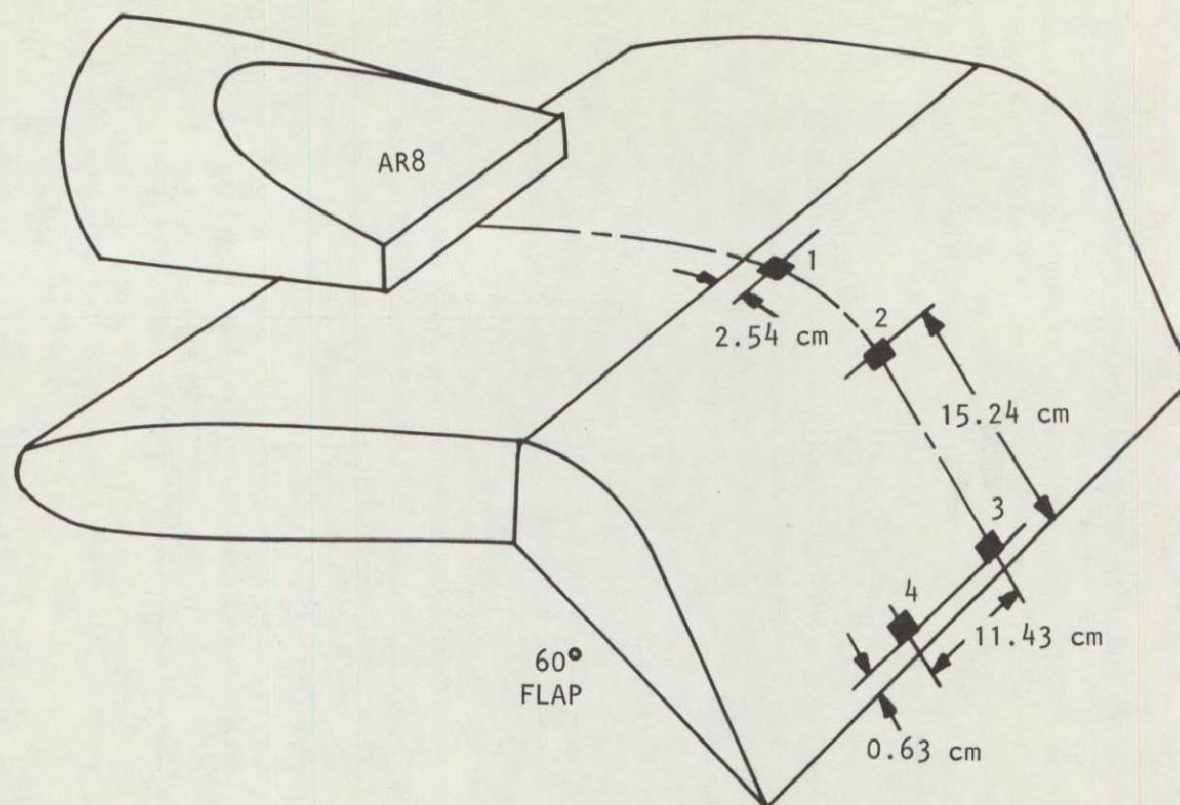


FIGURE 2-30 KULITE LOCATIONS

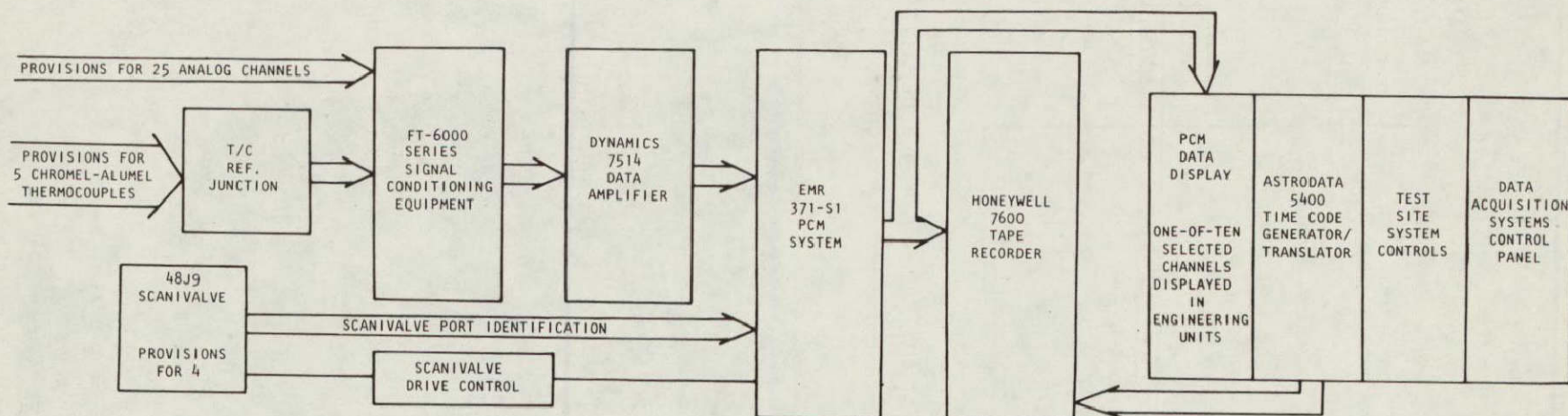
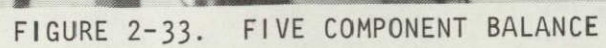
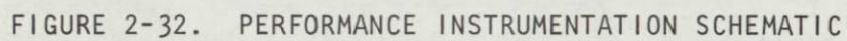


FIGURE 2-31. PERFORMANCE DATA ACQUISITION SYSTEM



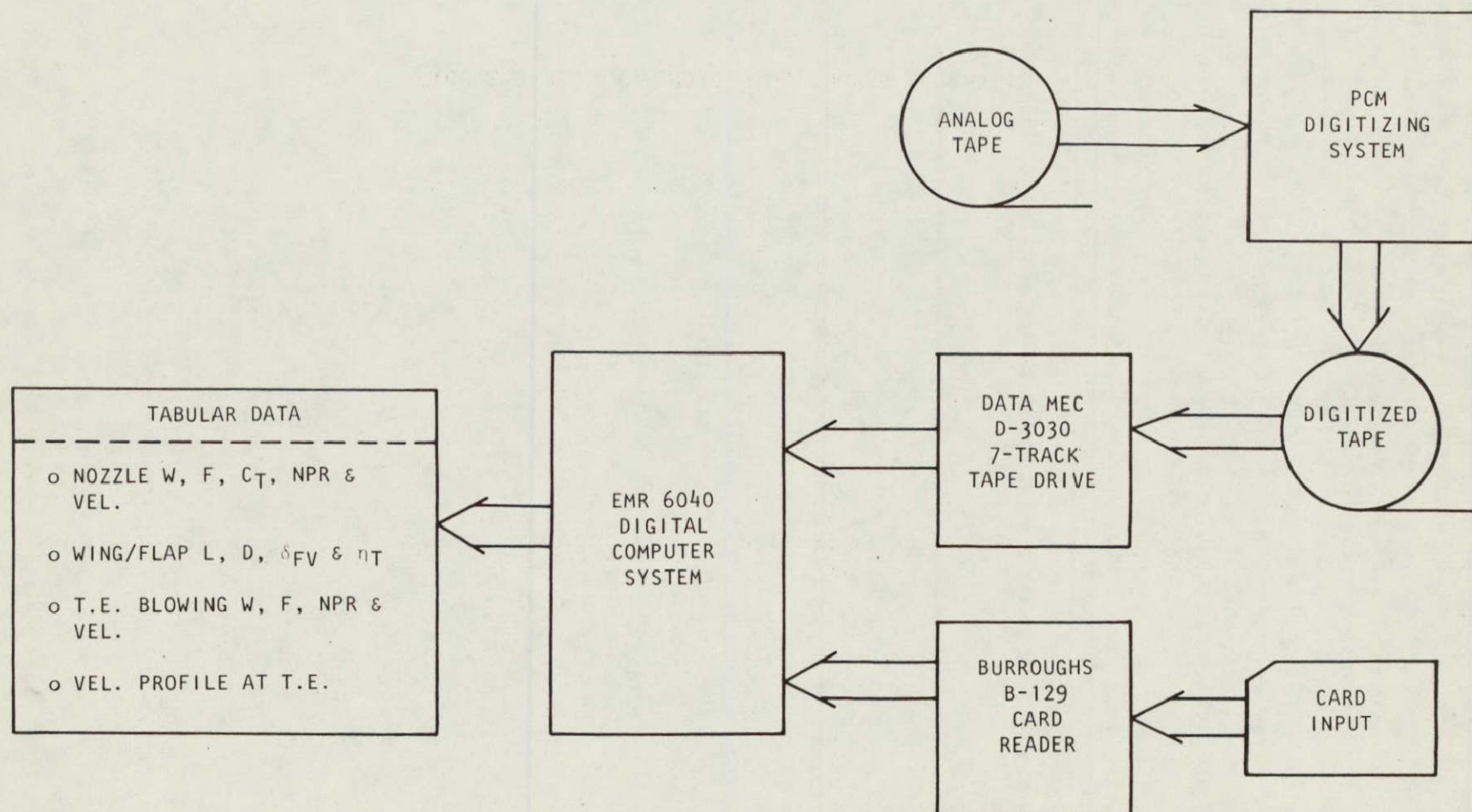


FIGURE 2-34. PERFORMANCE DATA REDUCTION SYSTEM

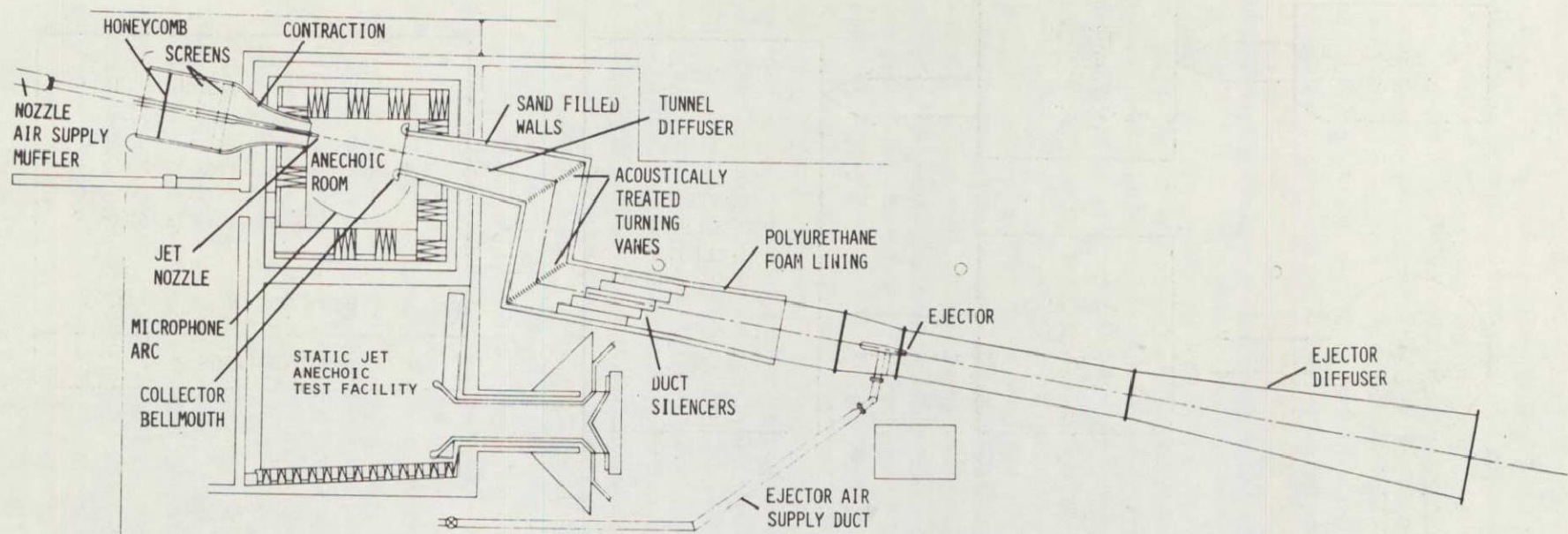
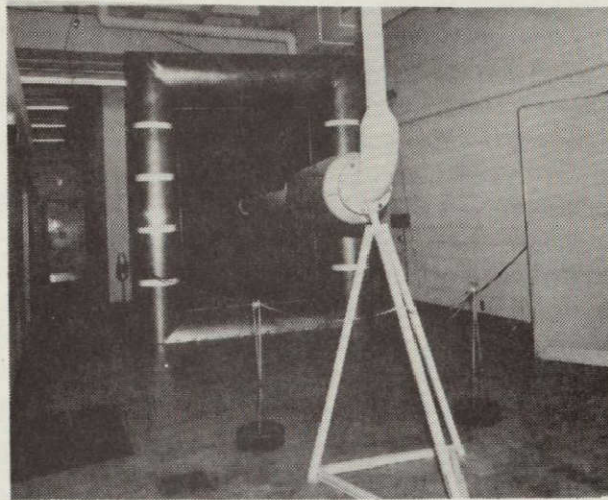
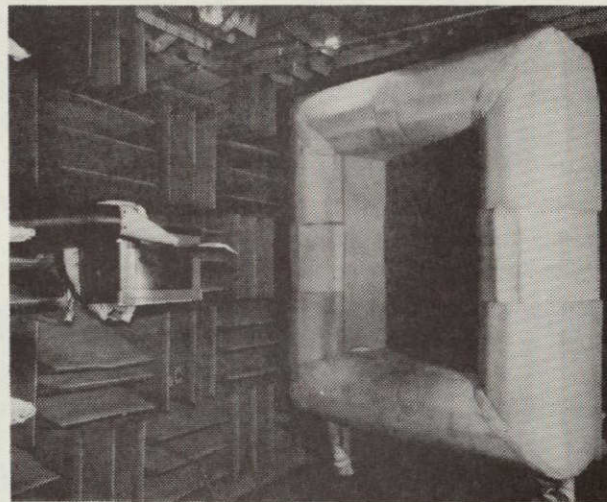


FIGURE 2-35. ANECHOIC WIND TUNNEL SCHEMATIC

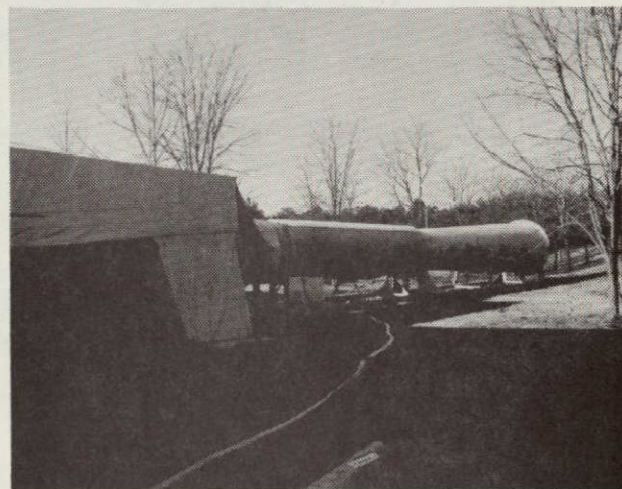
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a) TUNNEL INLET

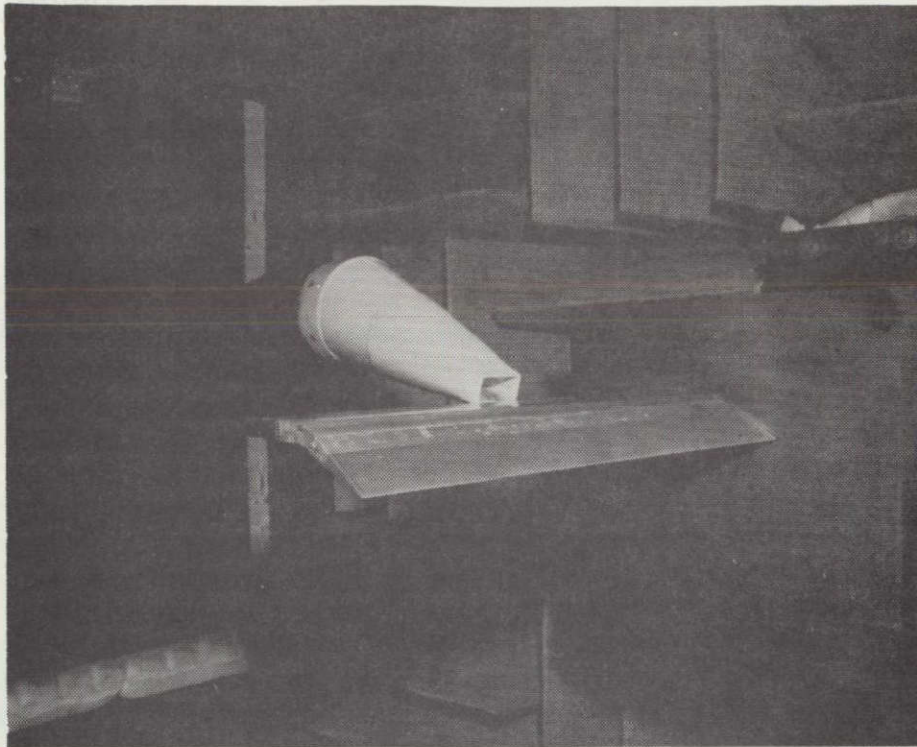


b) TUNNEL INTERIOR

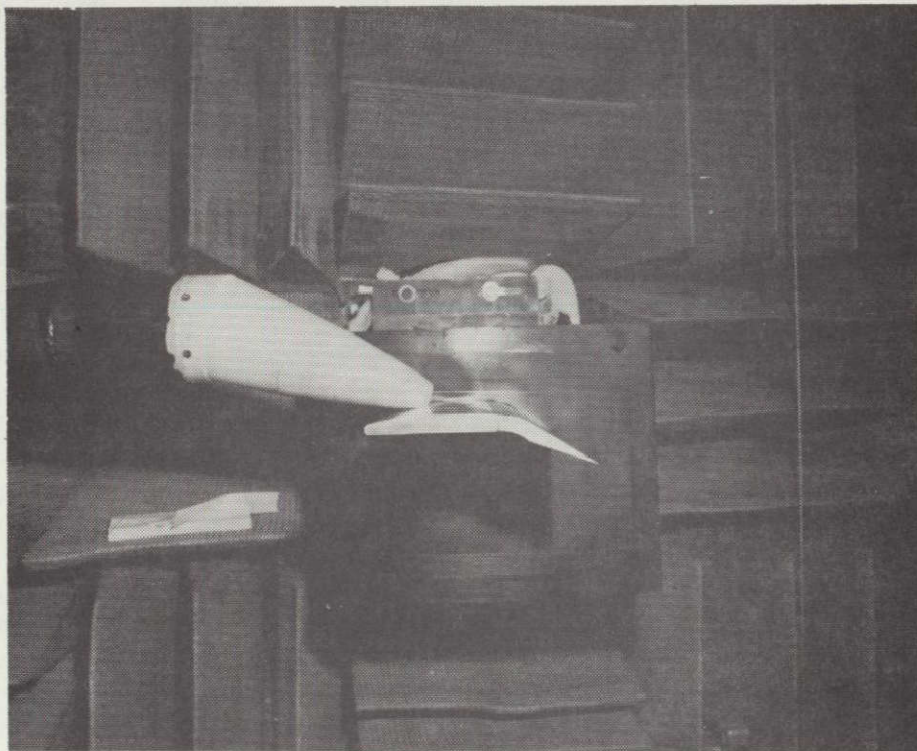


c) TUNNEL EXHAUST

FIGURE 2-36. ANECHOIC WIND TUNNEL

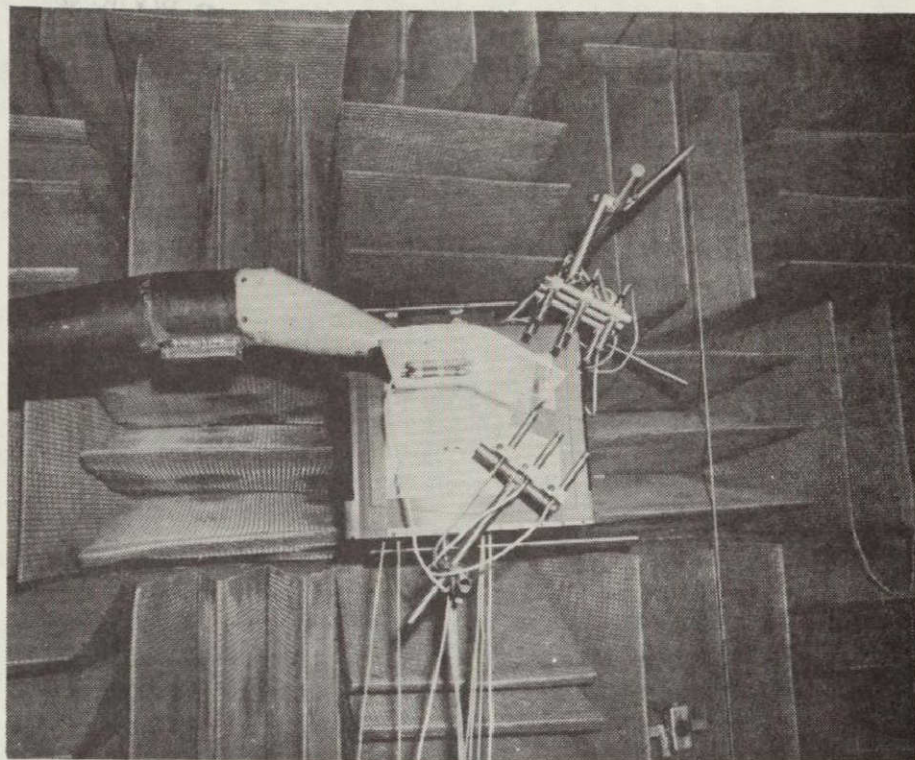


a) REAR QUADRANT VIEW

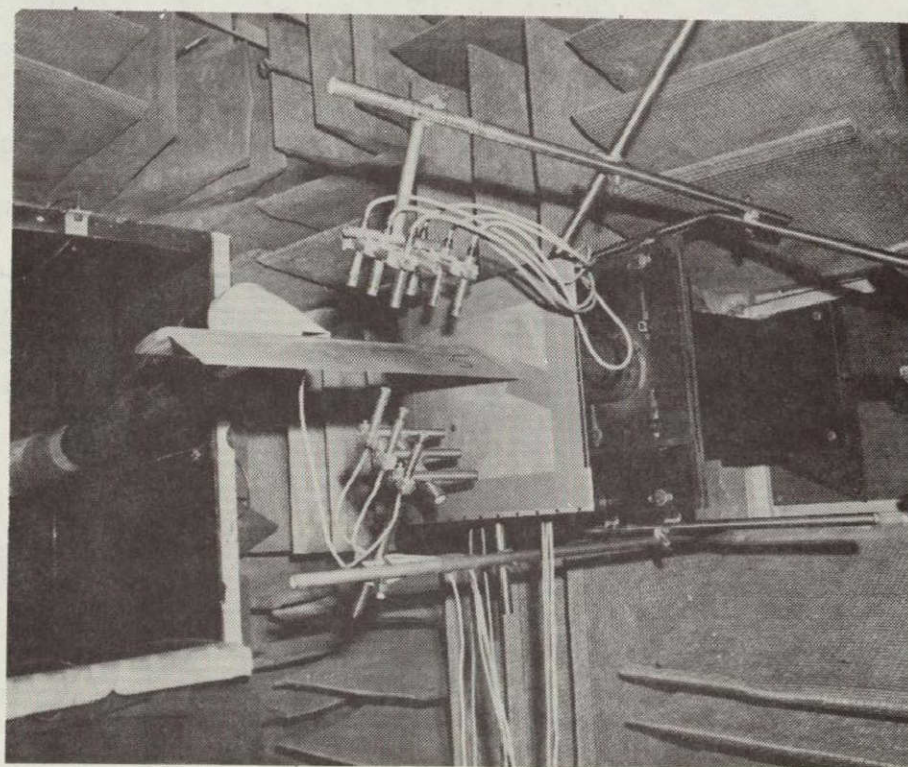


b) SIDE VIEW

FIGURE 2-37. ANECHOIC WIND TUNNEL MODEL



a) SIDE VIEW



b) REAR QUADRANT VIEW

FIGURE 2-38. NEAR FIELD MICROPHONE LOCATIONS

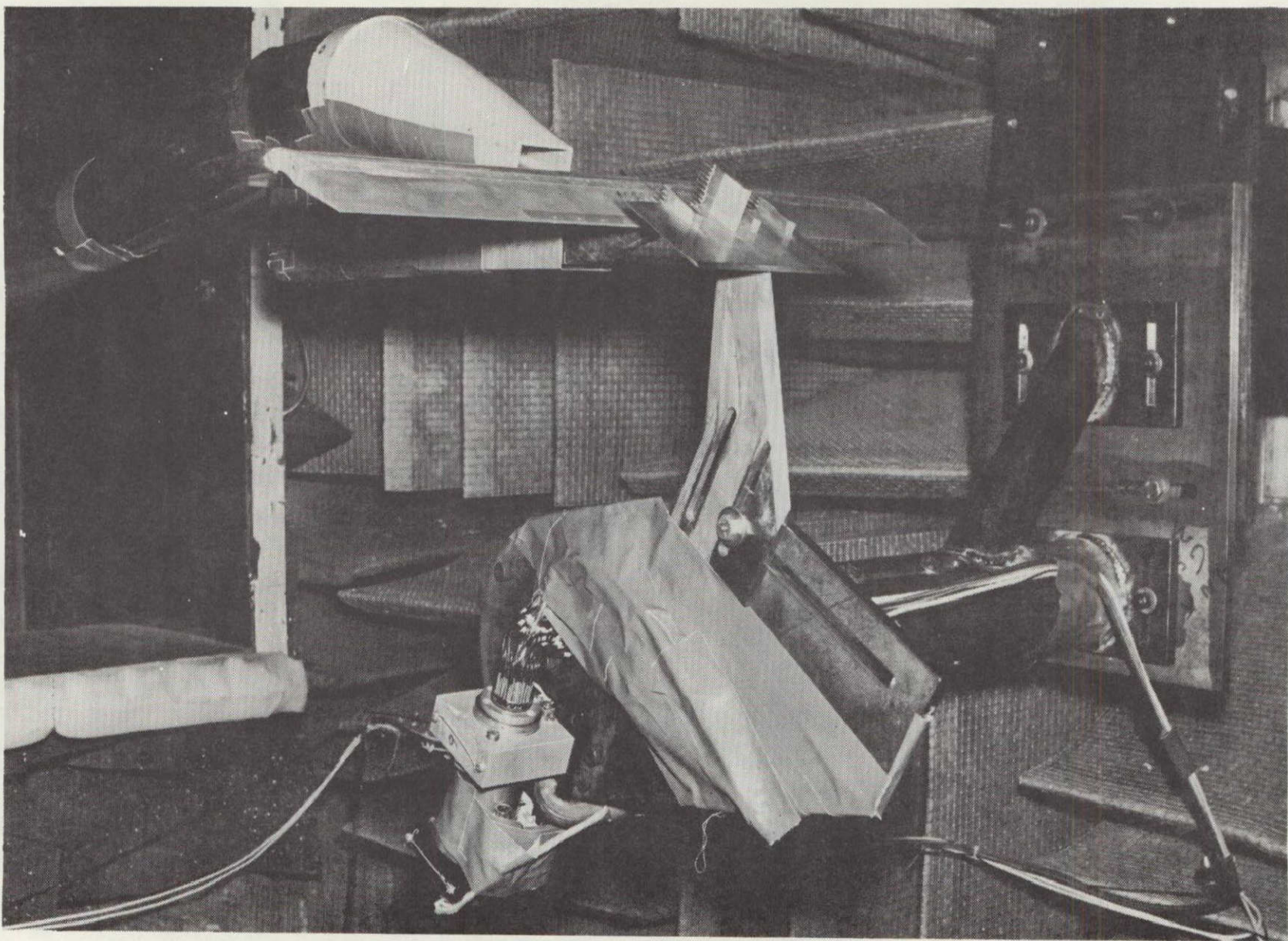


FIGURE 2-39. ANECHOIC WIND TUNNEL RAKE

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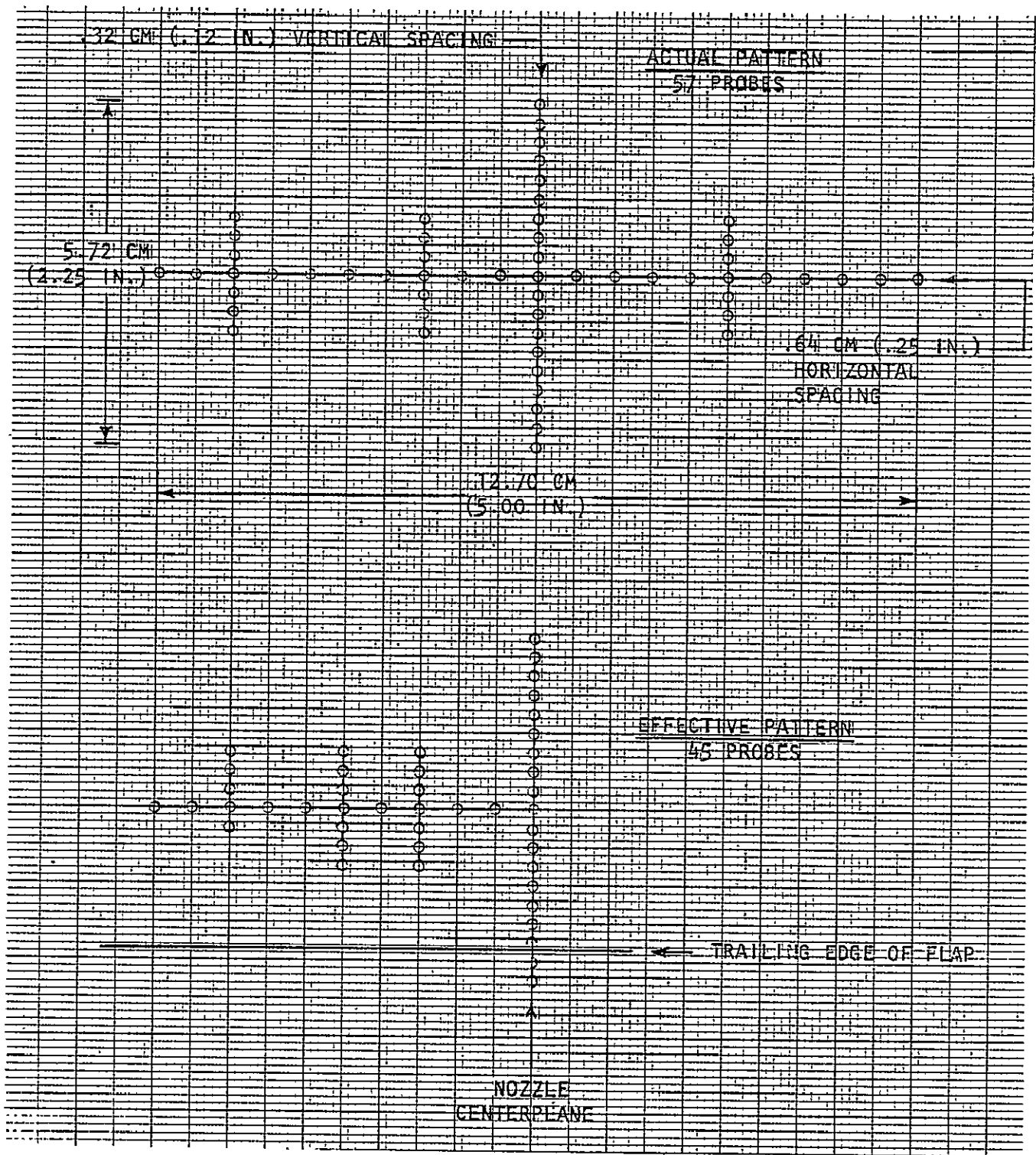


FIGURE 2-40. PROBE ARRANGEMENT - ANECHOIC WIND TUNNEL RAKE

3. FLOW FIELD AND PERFORMANCE RESULTS

3.1 FLOW VISUALIZATION

3.1.1 Oil Flow Patterns

Oil flow visualizations provide useful information about the flow/surface interface. In particular they show the extent of attached flow and the extent of scrubbed surface and scrubbed trailing edge.

3.1.1.1 Flow Attachment - The effects of various geometric parameters on flow attachment can be seen in the oil flow photographs, Figures 3-1 through 3-5. Caution is required, however, in the interpretation of what appear to be weakly attached flows. It is often difficult to distinguish between streaks which actually represent attached flow and those which only appear to be attached. The latter streaks can result from momentum imparted to the oil before flow separation and from the build-up of swept-back oil into a layer of sufficient thickness to reencounter the separated flow. This problem, however, is encountered only infrequently; most flow patterns are obviously attached or obviously separated.

The flow attachment observations are summarized in Table 3-1. Part A of the table shows the results of observations for a moderate radius, short length flap configuration with various combinations of nozzles, nozzle chordwise locations, and nozzle impingement angles. Part B is similar for the short radius flap at two nozzle locations; the longer trailing edge segments have the same flow length as the configurations of Part A. Part C shows the effects of NPR on flow attachment for some configurations of Part A. In these observations the flow was deemed attached if the surface was well scrubbed at the midspan of the trailing edge.

The interrelationships among the variables which affect flow attachment are complex, but the influences of individual variables can be seen in the table and in the photographs from which the table is derived.

Effect of Nozzle Shape - Nozzle shape influences flow attachment through such characteristics as the nozzle height, the nozzle width, the width of the nozzle/wing interface, and the nozzle roof angle as in the QCSEE nozzle. Nozzle height is an approximation to flow thickness, which, with velocity and flap radius, is a term in the surface pressure equations describing Coanda flow. Thinner flows are more easily turned, other conditions being equal. Nozzle width provides a measure of the degree of three-dimensionality which can be expected in the flow. Wider nozzles emit flows with relatively less edge mixing and pressure relief than narrow nozzles. The flow from wider nozzles is more similar to two-dimensional flow and is therefore more likely to remain attached. This can be seen by comparing the right photograph in Figure 3-4 with the left photograph in Figure 3-5.

The width of the common boundary between the nozzle and the wing is related to three-dimensionality of the flow in the same way as nozzle width. The effect of this common boundary width on attachment can be seen by comparing the left photographs in Figures 3-2(a) and 3-4. Roof angle affects flow thickness in the same way as nozzle height. Generally, the effects of nozzle size are the same as those of nozzle shape.

The effects of most of these parameters can be seen in Table 3-1. The effect of nozzle height on flow attachment, however, is not clear.

Effect of Nozzle Chordwise Location - Nozzle chordwise location on the wing strongly affects flow attachment. Part A of Table 3-1 contains a good

illustration of this in the 10° impingement angle results, where both the circular and elliptical nozzles produce separated flow when installed at 50% chord but yield attached flow when installed at 20% chord (Fig. 3-1). Chordwise locations refer to the 11.43 cm basic wing section exclusive of the variable flap and trailing edge segments.

Effect of Nozzle Impingement Angle - The major effect of impingement angle is to thin and spread the flow so that flow attachment is promoted. This effect can be seen in all three parts of Table 3-1. The flow thinning as impingement angle is increased can be inferred from the flow spreading seen in Figure 3-2. The effect on the circular nozzle is more dramatic than on the AR8 nozzle because of the large difference in initial contact width.

Effect of Vectored Thrust - The vectored thrust configurations, probably as a result of the higher impingement angles used, all delivered flows attached over wide regions of the wing. Vectored thrust configurations are raised and downward directed circular jets. In these cases, static test results are probably not very representative of the results which would be obtained with forward speed. However, the strong spreading characteristics could be expected to persist. Figure 3-3 shows the effect of nozzle height above the wing on a vectored thrust configuration. The major effect is the development of a separation bubble when the nozzle is close to the surface. Separation bubbles are discussed further in Section 3.1.1.2, in connection with flow spreading.

Effect of Flap Radius - Increasing the flap radius tends to promote flow attachment, as is shown in Figure 3-4. It can be seen that the flow over the short-radius flap separates more rapidly than over the more gentle radius along its outer edges and that the separation ultimately is complete.

Effect of Trailing Edge Length - Increasing the length of the trailing edge segment reduces the span of attached flow at the trailing edge. This may be seen in Figure 3-5, where the smaller width of scrubbed trailing edge is associated with the longer trailing edge segment. There appears to be little or no difference in the patterns when the short trailing edge segment is compared to the same length on the longer trailing edge. This suggests that the effects of trailing edge segment length on scrubbed width at the trailing edge result directly from the increased flow length rather than from flow field changes upstream of the trailing edge segment.

3.1.1.2 Flow Spreading - The effects of geometric and operational variables on flow spreading can also be seen in the surface oil flow photographs, Figures 3-1 through 3-5. In particular the photographs show the size and shape of the scrubbed surface and local flow separation followed by re-attachment. The flow widths at the start of curvature and at the flap trailing edge are significant. The width at the start of curvature is inversely related to the thickness of the flow at that location, and thin flows turn better than thick flows, other things being equal. The width at the trailing edge is a measure of the extent of strong interaction between the edge and the turbulent flow, which is thought to dominate USB noise generation and propagation. Finally, scrubbed area is a measure of the potential for increased lift due to blowing.

The flow spreading results, at a common nozzle pressure ratio of 1.55 for the blended nozzle configurations, are shown in Figures 3-6 and 3-7. Figure 3-6 shows the scrubbed trailing edge width and the scrubbed surface area as obtained from the oil flow photographs. Only the part of the surface which either is scrubbed fairly clean or is clearly streaked is considered

scrubbed for these purposes; the rather thick built-up area around the edges is excluded. Scrubbed area is computed as follows:

$$A_s = C \left(\frac{(W_N + W_W)}{2} L_W + \frac{(W_W + W_F)}{2} L_F + \frac{(W_F + W_{TE})}{2} L_{TE} \right)$$

where C is the correction from photograph dimensions to model dimensions. The widths at the nozzle exit, start of curved section, end of curved section, and trailing edge were measured from the photographs, all of which were taken from the same location and processed identically. The lengths between the measuring locations were obtained from the design drawings.

Effect of Nozzle Shape - Nozzle shape is seen to affect the three spreading characteristics — the widths at the flap and trailing edge and the scrubbed area — primarily through nozzle width. Wider nozzles scrub wider paths and more area. Nozzle size also has an effect, however, which appears more prominently at the higher impingement angles.

Effect of Nozzle Size - At grazing and small-angle impingement the flow widths and scrubbed areas appear to be determined primarily by nozzle width. At higher angles, size itself comes into play, and increased size and forced spreading can overcome the advantage of the wider nozzle. This is particularly evident when the circular nozzle is compared with others; both scrubbed widths and scrubbed areas increase faster with impingement angle for the circular nozzle than for the other nozzles.

Effect of Nozzle Chordwise Location - The effects of nozzle chordwise location on the wing are clearly shown in Figures 3-6 and 3-7. As the nozzle is moved forward on the wing and the total flow length is held constant, all three spreading parameters increase. The more forward

location scrubs wider at the flap and the trailing edge and therefore scrubs more area. The reason for this behavior is not immediately obvious. An order-of-magnitude Coanda analysis suggests the opposite behavior for the two-dimensional case without shocks. The flows considered herein are, however, poor approximations to two-dimensional flows.

Effect of Impingement Angle - As impingement angle is increased the flow spreads wider and thinner and is turned more effectively by the flap. The chordwise location of the nozzle affects the sensitivity of the flow to impingement angle, as can be seen in Figures 3-6, where the rate of increase in scrubbed area with increasing impingement angle is much less for the 50% chord location than for the 20%.

Effect of Vectored Thrust - Vectored thrust configurations usually operate at significantly higher impingement angles than blended nacelle designs. This is partly because a higher angle is required to overcome the effects of forward speed on the flow between the nozzle and the lifting surface and partly because the cruise penalty associated with high-angle impingement can be avoided by raising the flow to the streamwise direction at cruise. The pertinence of vectored thrust data without forward speed is subject to question, since the exposed vectored thrust jet at forward speed is more vulnerable to the freestream than is the flow from a blended nacelle. However, some observations are in order. The flow as seen in Figures 3-8 and 3-3 spreads wide, as might be expected at the higher impingement angle, and wider yet as nozzle clearance is increased. Forward flow over the wing leading edge can be seen in Figure 3-3(A). Forward speed would be expected to redirect this flow advantageously to a more spanwise direction.

Effect of Flap Radius - No clear trend in either scrubbed trailing edge width or scrubbed area can be seen in the oil flow photographs. Coanda turning considerations suggest that the flow is more likely to separate from a tight-radius flap than from a more gentle flap.

Effect of Trailing Edge Length - The effect of total flow length, as shown in Figure 3-9, is negligible relative to the data scatter.

3.1.2 Schlieren Photographs

Schlieren photography, being sensitive to density gradients in the flow field, can show some of the inner structure of the flow as well as its outer bounds. Schlieren techniques are helpful because they promote understanding of the flow field on a physical level.

Unless stated otherwise, the conditions applying to the Schlieren photographs are as follows:

- | | |
|-------------------------|-------------------------|
| o AR-8 Nozzle | o $R_C = 7.62$ cm |
| o $X_N = 0.2$ c | o $\delta_f = 60^\circ$ |
| o $\theta_N = 20^\circ$ | o $L_f = 21.77$ cm |
| o NPR = 1.47 | |

3.1.2.1 Effects of Flap Radius and Deflection - Figure 3-10 shows the effects of varying R_C and δ_f with other flow conditions constant. (The length of the flap trailing edge segment was varied to maintain a constant flow length.) It can be seen that:

- o The thickness of the flow field at the trailing edge increases with flap deflection and appears to be relatively independent of flap radius.
- o The flow at $\delta_f = 60^\circ$ appears to be coarser in scale than at the lower deflection angles. The greater change occurs between $\delta_f = 45^\circ$ and $\delta_f = 60^\circ$.

- o The spreading angle below the wing is fairly insensitive to both R_C and δ_f .

3.1.2.2 Effect of Impingement Angle - Figure 3-11, covering the range of θ_N from 0° to 30° , shows that:

- o The flow is separated at 0° , weakly attached at 5° , and strongly attached at 10° and 20° .
- o The thickness of the flow near the trailing edge is greater when the flow is less firmly attached, as at 0° and 5° impingement angles.

The dark band extending into the flow from the flap except at $\theta_N = 20^\circ$ is related to separation and roll-up along the spanwise edges of the jet.

3.1.2.3 Effect of Trailing Edge Length - Figure 3-12 shows the basic 60° flap and an undeflected flap, each at three flow lengths. The photographs show no significant effect of trailing edge length.

3.1.2.4 Effect of Nozzle Chordwise Position - The configurations of Figure 3-13 have a common trailing edge length. The flow thickness on the curved portion of the flap is seen to decrease as the nozzle is moved nearer the flap. This phenomenon of reduced flow thickness is expected, since the more aft locations of the nozzle offer less opportunity for jet growth before the curved portion of flap is encountered.

3.2 SURFACE PRESSURES

Static and fluctuating pressures were measured at the upper surface of the wing along the midspan line and selected spanwise lines. The static

pressure distribution is indicative of the amount of jet turning achieved and therefore of the performance capability of the system. The fluctuating pressures represent structural fatigue loads and are related to the generation and propagation of sound in the region above the wing.

3.2.1 Static Pressures

Pressure profiles are shown in Figures 3-16 through 3-20. Figure 3-18 shows spanwise profiles; the others are streamwise. The effects of the wing upper surface contour and of the small discontinuity between the wing and the flap can be seen in the axial profiles. The discontinuity consists of a slight gap (~ 0.02 cm) between the curvature of the wing surface and the flap radius.

3.2.1.1 Effect of Nozzle Chordwise Location - The chordwise location of the nozzle on the wing directly affects the velocity and thickness of the flow over the flap. These variables affect the ability of the flow to remain attached and to reduce the static pressure over the wing. Figure 3-16 shows the axial distributions of surface pressure over a representative flap as a function of nozzle chordwise location for impingement angles of 0° and 20° . The major effect, other than separation, occurs on the wing near the nozzle in the 20° impingement case. As the nozzle is moved toward the flap, the wing static pressure becomes less negative. The forward-most surface pressure measured is near ambient with the nozzle at 20% chord; at 35% and 50% chord the pressures become increasingly positive as they reflect the impact pressure from the inclined nozzle. With 0° impingement angle the flow is separated and the surface pressures are independent of nozzle location over the wing portion of the surface. Figure 3-17 highlights the differences between the surface pressure profiles for attached and separated flows.

At either 0° or 20° impingement angle the minimum surface pressure becomes more negative as the nozzle location is moved aft, as can be seen in Figure 3-16. This is to be expected because the absolute velocity of the flow is increased, thereby making increased suction possible. In the case of 0° impingement moving the nozzle aft appears to change the location of the minimum pressure as well as its magnitude. It is not clear why the 35% chord location should appear more favorable for attachment than 20% or 50% chord.

A comparison of parts A, B, and C of Figure 3-18 shows that the chordwise location of the nozzle has little effect on the spanwise pressure distribution at the start of curvature but has a considerable effect at the end of flap curvature. At the end of curvature the flow tends toward separation along the midspan line while attachment is maintained outboard. As expected, flows which impinge at higher angles are less affected by the chordwise location of the nozzle than are more tangential flows.

3.2.1.2 Effect of Flow Impingement Angle - Increasing the flow impingement angle promotes flow attachment by forcing the jet to spread over a large area. The axial pressure profiles of Figure 3-19 illustrate that point well - the higher the impingement angle, at any nozzle chordwise location, the better the flow attachment and the suction pressure on the upper surface. The pressure profiles as in Figure 3-19(D) show larger distances to the centerline separation point as the flow impingement angle is increased. Figure 3-18 shows similar behavior in the spanwise distribution. The area of reduced pressure increases with increasing impingement angle.

3.2.1.3 Effect of Nozzle Pressure Ratio - As is shown in Figure 3-20, nozzle pressure ratio has a very slight effect on the axial pressure profile. The minor effect is to decrease the magnitude of the suction pressure coefficient as nozzle pressure ratio is increased. A comparison of Figures 3-19(A) and (D) shows similarly directed but more intense effects on the flows which are less firmly attached than that at the higher impingement angle. Higher pressure ratios appear to promote separation.

3.2.2 Fluctuating Pressures

The midspan and trailing edge ports used for static pressure measurements were enlarged to accommodate the 0.2-cm diameter probes of the microphones. The microphones were mounted from the lower surface of the wing. The port locations are shown in flat pattern in Figure 3-21. One- and two-point correlations were obtained using the H-P 1621 correlator.

3.2.2.1 Correlations - Autocorrelations of fluctuating surface pressures were made along the midspan line of the flap and along the trailing edge line of pressure ports. Figures 3-22 and 3-23 are typical autocorrelation functions measured at several streamwise locations along the midspan of the curved flap and straight section respectively.

The magnitude of the autocorrelation at zero time delay is the mean square value of the fluctuating signal. Figure 3-24 shows the distribution of the maximum (or zero-delay) autocorrelation. As is indicated by the faired line through the data points, the net intensity of the fluctuating pressure tends to increase as the flow is turned and then to decrease as the flow passes down the flat trailing edge. The scatter in the region of the contour change is attributed to the slight discontinuity of the flap-to-trailing-edge joint.

The humps and oscillatory tails in the autocorrelations suggest periodicity in the fluctuating pressures. The humps, which peak between 765 and 900 microseconds, indicate a 1300-to-1100-Hz periodicity. The peak spacing in the tails is about 265 microseconds, which corresponds to 3800 Hz.

Autocorrelations made spanwise along the line of trailing edge ports are shown in Figure 3-25, and the spanwise distribution of the peak autocorrelation at trailing edge is shown in Figure 3-26. The distribution of intensity is shown to peak approximately 3.5 cm from the midspan line and then to drop sharply with increasing distance outboard. A comparison of this profile and the oil flow photograph (Figure 3-27) shows that the peak intensity occurs in the region where an inward flow of entrained air scrubs the surface. Apparently the separated flow farther from the midspan contributes little to fluctuating surface pressures. The periodicity observed along the midspan line is also observed along the trailing edge.

Streamwise space/time correlations were made with the downstream signal delayed (Figure 3-28). The peaks, which diminish in magnitude and occur at later times as the separation between the probes is increased, are indicative of a broad-band pressure field which is convected downstream. The convection velocity of the field is discussed in the next section. The streamwise space/time correlations themselves display the same periodicity as is seen in the autocorrelations.

Spanwise space/time correlations were made using the trailing edge ports. The correlation functions, shown in Figure 3-29, were made with the outboard signal delayed relative to the midspan. Delaying the midspan signal makes little difference in the correlation functions — they still look like autocorrelations. This is indicative of a lack of spanwise convection. The

low levels of the space/time correlations relative to the autocorrelations show a lack of spanwise coherence in the pressure field.

3.2.2.2 Convection Velocity and Length Scale - A convection velocity was obtained for the fluctuating pressure field in the same way that convection velocities are obtained for fluctuating velocity fields. Figure 3-30 is a plot of microphone separation distance versus delay time to the peak of the corresponding space/time correlation. The slope of the straight-line curve fit is 169 m/sec, which is approximately $0.66 V_j$.

The magnitudes of the streamwise and spanwise space/time correlations at zero delay time are plotted versus probe separation distance in Figure 3-31. The separation distance to the zero crossing point is interpreted as a typical length scale of the convecting pressure field. The spanwise length scale is 2.1 cm. Because of the coarse spacing of the spanwise ports, the curve faired through the data points is much more tentative than the one for the streamwise data. However, the length scale appears to be about 2 cm.

3.3 VELOCITY AND TURBULENCE PROFILES

3.3.1 Nozzle Characteristics

3.3.1.1 Validation Profiles - Nozzle exit velocity and turbulence intensity profiles were determined in some detail on the small-scale models to assure that the nozzles provided suitable flow characteristics. The profiles were plotted on-line from the output of a linearized hot-wire anemometer using tungsten wires with an active section 5 microns in diameter and 0.2 cm long. The hot-wire probes were traversed across the flow field in a plane

approximately 0.32 cm from the exit plane; a closer approach invites probe damage by very low frequency oscillations of the probe support structure. Also, to avoid undue wire breakage, the profiles were made at a 1.1 nozzle pressure ratio.

The validation profiles are shown in the following figures:

<u>Figure</u>	<u>Nozzle</u>
3-32	Circle, 5.08 cm dia.
3-33	Ellipse
3-34	D-shape
3-35	AR-2
3-36	AR-4
3-37	AR-8
3-38	QCSEE

The mean velocities (dashed lines) and turbulence intensities (solid lines) are plotted together to facilitate comparison; mean velocity and turbulence intensity are interrelated so that whatever changes one also changes the other.

In general the mean velocity profiles are flat topped and fall off quite rapidly at the edges, while the turbulence intensity profiles have sharply defined peaks on the lip lines and are flat in between. The usual turbulence intensity levels are 6-10% at the peaks and less than 1% in the bulk of the flow. These levels are acceptable for the present work.

The slightly skewed profiles in Figures 3-35(E) and (H) result from a slight asymmetry in internal contour in the upper right-hand corner of the AR-2 nozzle. The scale of the plot accentuates the imperfections, which

are actually small ~5.5% peak turbulence and a small velocity defect in the corner.

3.3.1.2 Discharge Coefficients - The wing partially blocks the nozzle, reducing the mass flow below that of the bare nozzle. Discharge coefficients, defined as the ratio of actual mass flow to ideal mass flow based on nozzle pressure ratio and nominal nozzle exit area, were obtained as functions of impingement angle. A calibrated-nozzle flowmeter was used with the small-scale model and a thin-plate orifice meter was used with the large-scale model.

Discharge coefficients for the small-scale nozzles are shown in Figure 3-39. Nozzles with a large flat surface in contact with the wing should be more sensitive to impingement angle than nozzles with a rounded contact surface which permits more freedom for lateral spreading. The QCSEE nozzle seems to be an exception in that it behaves more like the elliptical nozzle than like the AR-2 nozzle. Perhaps the side doors permit equivalent lateral spreading.

Discharge coefficients for the large-scale model are shown in Figure 3-40 as functions of impingement angle and jet exit velocity.

3.3.2 Small-Scale Profiles

Velocity and turbulence intensity profiles were made just downstream of the trailing edge and farther downstream in the wake. The static profiles were obtained using a single-channel linearized hot-wire anemometer with the wire parallel to the trailing edge. The profiles with forward speed were obtained with a total pressure rake.

3.3.2.1 Trailing Edge Profiles - Trailing edge profiles, plotted in Figures 3-41 through 3-54, show either the mean velocity profiles or the turbulence intensity profiles for the various nozzles at the following conditions:

$$X_N = 0.20 \quad \delta_f = 60^\circ$$

$$\theta_N = 20^\circ \quad L_{te} = 3.81 \text{ cm}$$

$$R_c = 5.08 \text{ cm} \quad L_f = 16.69 \text{ cm}$$

Mean velocity and turbulence intensity are normalized to jet exit velocity and plotted versus height above the surface normalized to nozzle height. Profiles are shown for several spanwise locations normalized to the half-widths of the nozzles. Figures 3-55 and 3-56 are comparisons of the mid-span mean velocity and turbulence intensity profiles, respectively, for the various nozzles.

Figures 3-57 through 3-62 are midspan profiles for various nozzle/flap configurations. In these figures mean velocity or turbulence intensity, normalized to jet exit velocity, is plotted against unnormalized height above the trailing edge.

Figure 3-57 shows the trailing edge velocity and turbulence profiles for all nozzles. The elliptical, D, and AR-2 nozzles have lower peak velocity ratios because of their smaller size. Compared to the circular nozzle, the AR-4, AR-8, and QCSEE velocity profiles peak nearer the surface and at lower velocities, since their thinner jets turn more readily than the circular jet but decay faster. Little effect of nozzle size or shape is seen in the turbulence profiles.

The very strong effect of flow impingement angle is shown in Figure 3-58. The flow is seen to be well attached and turned, poorly turned, and separated at $\theta_N = 20^\circ$, 10° , and 5° , respectively. The turbulence profiles vary considerably, particularly between the attached and separated cases.

It is a little surprising that the 10° case shows a higher peak near the surface than does the 20° case. What this may mean is that the 20° case lags the 10° case in centerline turbulence development. The oil flow photographs show the inflow of entrained air along the surface to approach the midspan line much more closely in the 10° case than in the 20° case. Lateral transport of the mixing-generated turbulence would tend to promote the development of midspan turbulence more at 10° impingement angle than at 20° . The 0° case lacks sufficient shear to generate much turbulence.

Flap deflection affects midspan velocity and turbulence as shown in Figure 3-59. Smaller deflection angles promote attachment and turning and tend to decrease turbulence intensity in the outer mixing region. The larger change in mean velocity profile between 45° and 60° than between 30° to 45° suggests that a limit in flow turning ability is being approached.

The effect of nozzle chordwise location on the wing is shown in Figure 3-60. The mean velocity increases and the velocity peak moves closer to the surface as the nozzle moves toward the trailing edge. The turbulence intensity increases also. Better turning is apparently achieved when a straight section follows the curved section rather than precedes it.

This may be because the longer trailing edge allows a more gentle adjustment from the Coanda-reduced pressure on the curved surface to the trailing edge conditions.

The effect of increasing trailing edge length is seen in Figures 3-61 and 3-62 for 7.62-cm and 5.08-cm flap radii, respectively. In both cases increasing the trailing edge length reduces the peak velocity and broadens the mean velocity profile. The effect on the location of the peak velocity, however, is different for the different radii. In Figure 3-61(A) the peak occurs nearer the surface with the shorter trailing edge than with either of the longer trailing edges, which have similar peak locations. In Figure 3-62 the peak occurs slightly nearer the surface with the long trailing edge than with the short one. The reason for this behavior is not known. Turbulence intensity decreases with increasing trailing edge length, as is seen in Figure 3-61(B).

The effects of flap radius of curvature are seen in Figures 3-63. Decreasing the radius of curvature reduces the peak velocity and increases the peak turbulence intensity levels.

3.3.2.2 Effects of Forward Speed - Jet velocity contours at the trailing edge of the flap were measured in the anechoic wind tunnel with the rake installation shown in Figure 2-39. Figure 2-40 shows the probe pattern. The velocity ratio contours obtained in the twelve tests are shown in Figure 3-64, with the 30° flap contours at the top, the 60° at the bottom, tunnel speed increasing from page to page, and each plot split right and left to show the two jet velocities. Several trends are apparent -

- o The jet spreads laterally and flattens as forward speed increases. Lobes of relatively high velocity appear beyond the edges of the nozzle at the highest forward speed.

- o The velocity ratios in the upper portions of the jet generally approach V_O/V_J , as would be expected. Velocity ratios less than V_O/V_J in two of the tests may be due to experimental error.
- o With 30° flaps, the core of the jet hugs the surface except at the highest tunnel speed. With 60° flaps, the core is about 1.5 nozzle heights off the surface throughout the speed range.
- o When the core is off the surface, the region under the core appears to be fairly well ventilated with freestream air, as there are few indications of velocity ratios less than V_O/V_J .
- o Even in terms of velocity *ratio*, the core of the higher-velocity jet reaches the trailing edge with less dissipation than does that of the lower velocity jet.

3.3.2.3 Wake Profiles - Profiles extending several nozzle heights down the wake are presented for the AR-8 nozzle alone and for a representative configuration using that nozzle. The mean velocity and turbulence intensity profiles for the AR-8 nozzle are shown in Figures 3-65 and 3-66. They cover a matrix of three spanwise locations (midspan, $Y = \frac{1}{4}W$, and lipline) by five streamwise locations.

More three-dimensionality appears as the profiles are viewed at locations farther from the midspan. Relative to the midspan profiles the mean velocity profiles at $Y = \frac{1}{4}W$ are rounder but have similar peak levels. At the lipline, the peak velocities are reduced to less than 60% of the jet velocity and some asymmetry is seen in the profiles. The turbulence profiles at midspan and $Y = \frac{1}{4}W$ are typical of developing flows, with peaks in the mixing region and a lower level in the central part of the flow. A

comparison of the midspan and $Y = \frac{1}{4}W$ profiles shows essentially the same central levels but much higher mixing region turbulence at $Y = \frac{1}{4}W$. At the lip line the turbulence profiles have the rounded peaks associated with developed flows, and the lower peak levels indicate a decaying turbulence field. The mean velocity asymmetries at $Y = \frac{1}{4}W$ appear to be amplified in the turbulence peaks.

Wake profiles for a typical configuration are given in Figures 3-67 and 3-68. These mean velocity and turbulence profiles cover a region of four spanwise locations by nine chordwise locations, $Y = 0, 1/4, 3/8$, and $1 W$ by 0.76 to 17.78 cm. The configuration is that for which turbulence correlation data were obtained.

Figure 3-67(A) shows clearly the initially steep and rapidly changing velocity gradients in the inner mixing region opposed to the gentle and slowly changing gradients in the outer region of the flow. Similar behavior is shown in parts B, C, and D of Figure 3-67 for locations off the midspan plane. This behavior results from the difference between the newly-initiated mixing at the inner boundary of the jet and the established well-developed mixing at the outer boundary. Further, it is noted that the maximum shear is found in the midspan plane. It is inferred from this that three-dimensional effects reduce the potential for entrainment and mixing at least as far from the nozzle edge as $\frac{Y}{W} = 0.25$.

The turbulence intensity profiles of Figure 3-68 are cross-plotted in Figure 3-69 for several values of Z' . The maximum rate of increase of turbulence with streamwise distance may be seen to occur slightly below (~ 0.25 cm) and slightly after (~ 2.54 cm) the trailing edge. The analysis report discusses the importance of this region in noise generation.

3.3.3 Large-Scale Tests

3.3.3.1 Flow Visualization - Surface oil flow photographs of the large-scale model were taken for flow visualization. The results at the two scales are compared in Section 3.3.4. Generally the two sets of flow patterns are similar.

Effects of Nozzle Aspect Ratio, Flap Deflection, and Impingement Angle -

Figures 3-70 and 3-71 show the oil flow patterns for the AR-4 and AR-8 nozzles at 30° and 60° flaps with three impingement angles. Impingement angle is seen to be an important variable for flow spreading. Other observations are:

- o As the impingement angle increases spreading increases, particularly before the curved section.
- o Over the curved surface and near the trailing edge the profiles differ considerably with flap deflection. With 30° flaps the flow lines tend to remain fairly straight with only a gentle convergence of the central lines toward the midspan. At 60°, however, the convergence is very strong so that S-shaped flow lines rapidly approach the midspan.
- o The patterns produced by the AR-8 nozzle on the 60° flap are more gentle than those from the AR-4 nozzle at the same deflection. They converge only a little more rapidly than the AR-4 30°-deflection paths.

Effect of Nozzle Height Above Wing - Figure 3-72 shows the flow patterns from a circular nozzle both on and off the wing for 30° and 60° flap angles and for 20° and 40° impingement angles. The following observations are made:

- o A separation bubble occurs with the nozzle on the wing at 20° impingement angle and 60° flaps. At 40° impingement the bubble is absent.
- o There is forward flow in all configurations but particularly in the off-the-wing configuration.
- o Even though exactly comparable configurations are not available, the 30° flap seems to have more gentle profiles with less inward flow than does the 60° flap.

Effect of Nozzle Deflector - Figure 3-73 shows oil flow patterns for the AR-4 nozzle with a deflector which simulates a translating shroud intended to improve low-speed performance by changing the impingement angle. The deflector angle is 12° and the nozzle angle is 14° . The flow impingement angle is taken to be the average of the inner (nozzle) angle and the outer (nozzle + deflector) angle: 20° . A comparison with corresponding configurations for the bare AR-4 nozzle (Figure 3-70) shows more spreading with the deflector - equivalent to more than 20° impingement with the bare nozzle but less than 30° . This seems to be the result of flow blockage by the deflector. The blockage effectively increases the aspect ratio of the nozzle and provides side opening for lateral spreading. Acoustic data for this configuration can be found in Reference 1.

Effect of Side Doors - Another nozzle which has a high roof angle and is open for lateral spreading is the QCSEE nozzle. Figure 3-74 shows surface flow profiles for 30° flap deflection and the design nozzle angle of -4° which yields a nominal flow impingement angle of 16° . The side doors were set at 0° (corresponding to cruise), 15° , and 25° (corresponding to take-off). Wide spreading is observed when the side doors are fully open. When the doors are closed, relatively little spreading is seen.

3.3.3.2 Pitot Profiles - Velocity profiles at the trailing edge were obtained using a 73-port total pressure rake. Midspan velocity profiles normalized to jet exit velocity were made for the conditions shown in Table 3-2. All profiles were measured with an ambient temperature jet at the 20% chord location. Selected profiles compared below show the effects of several variables on the mean velocity profiles. The comparisons are made at selected nozzle pressure ratios, since nozzle pressure ratio had little effect on the peak velocity ratio or on the shape of the profile.

Nozzle Shape - Midspan velocity profiles for the AR-4 and AR-8 nozzles at essentially the same conditions are compared in Figures 3-75(A) and (B). At $\delta_f = 60^\circ$ the profile for the thinner AR-8 nozzle has a lower peak velocity which occurs much nearer the wing than does that for the AR-4 nozzle. As a consequence of the higher peak velocity the AR-4 nozzle also has a steeper velocity gradient near the surface. The steeper gradient implies higher turbulence generation rates which suggest greater noise. At $\delta_f = 30^\circ$ there is little difference in profile shape other than that resulting from the generally higher velocity levels for the AR-4 nozzle. The larger hydraulic diameter of the AR-4 nozzle is the reason for the higher overall velocities.

Impingement Angle - Midspan velocity profiles are compared at various impingement angles in Figure 3-75(C) through 3-75(F) for both nozzles at both flap deflection angles. The general effect, seen in all parts of the figure, is that the level of the profiles diminishes with increasing impingement angle. There is little change in shape except for a tendency at $\delta_f = 30^\circ$ for the velocity peaks to move nearer the surface as the impingement angle is increased.

Flap Deflection - The effects of flap deflection can be seen in previously examined Figures 3-75(A) through (F) and more directly in Figure 3-75(G) and (H). With either nozzle the profile generally flattens as the deflection angle increases from 30° to 60° : the peak velocity diminishes and occurs farther from the surface and the profile is much broader. The broadening effect is much more pronounced with the AR-4 nozzle than with the AR-8 nozzle, presumably because it is more difficult to turn a relatively thick and narrow jet.

3.3.3.3. Trailing Edge Isotachs - The mean velocity profiles at various spanwise locations were cross-plotted to obtain the velocity ratio contours shown in Figures 3-76 through 3-78. These contours show the spreading and edge roll-up characteristics seen at the flap trailing edge.

Flap Deflection - Figure 3-76 shows flap deflection effects for the three nozzles, AR-4, AR-4D, and AR-8. The shapes of the velocity contours for the AR-4D nozzle are least affected by changing flap deflection — the contours stay rectangular and become larger with increasing deflection. The AR-8 contours show increasing edge roll-up and overall thickening as δ_f increases. Most changed are the contours for the AR-4 nozzle. They

change from a pattern much like the AR-8 pattern at 30° flaps to a bell shape at 60°.

Nozzle Shape - Contours for the AR-8 and AR-4 nozzles may be compared in all of the isotach figures, 3-76 through 3-78. Direct comparisons are shown in Figure 3-77. Figure 3-76, however, shows the AR-4 nozzle with a deflector (AR-4D) in addition to the other nozzles. As indicated in the centerline profiles, the AR-8 nozzle has wider and flatter isotachs than the AR-4 nozzle. The AR-4D nozzle has very flat profiles as a result of the deflector, even though θ_N is reduced to 15° compared to 20° for the other nozzles. At 30° flaps the lateral flow spreading for the AR-4D is of the order of that for the AR-8 nozzle; at 60° flaps it is greater.

Jet Velocity - The effects of increasing jet velocity from 215 m/s to 285 m/s can be seen by comparing parts (A) and (B) of Figure 3-77. As is noted in Section 3.3.3.1, increasing the jet velocity increases the level of the profiles with little other change, at least near the midspan. The bulge near the surface suggests spreading caused by jet impingement on the surface, but a similar explanation for the upper bulge at low velocity is not evident.

Flow Impingement Angle - Figure 3-78 shows comparative isotachs for $\theta_N = 10^\circ$, 20°, and 30° using the AR-4 nozzle and 60° flap. As is indicated by the midspan profiles the inner profiles and the location of the peak move toward the surface as impingement angle increases. Surprisingly little lateral spreading is seen near the surface. What is seen instead is a filling out of the concave lateral surface.

3.3.3.4 Hot-Wire Profiles - Hot-wire turbulence with the large-scale model was measured 2.54 cm downstream of the trailing edge of a representative configuration. Mean velocity and turbulence profiles were obtained in the midspan plane and in the lipline plane. Figure 3-79(A) shows the midspan and lipline mean velocity profiles as obtained by hot-wire and pitot probes. Good agreement is seen between the two sets of profiles except in the outer portion of the lipline profiles, where the hot-wire data are considerably higher than the pitot data. This discrepancy is attributed to the differences in yaw sensitivity between the two probes. The hot-wire probe recovers all the Y component and, at yaw angles greater than about 30°, more of the Z component than does the square-edged pitot probe. The midspan agreement is consistent with local two-dimensionality of the flow at that location.

The peak turbulence intensities in Figure 3-79(B) are of the same order of magnitude as those of the small-scale model (Figure 3-68), but the profiles differ in shape. The lower part (small Z) of the profile (up to the peak) is quite similar; after the peak the small-scale data fall off quickly, as is consistent with the smaller absolute thickness of the flow.

3.3.4 Scale Effects

3.3.4.1 Surface Oil Flow Pattern - Photographs of surface oil flow patterns on the large-scale and small-scale models for similar conditions are shown in Figure 3-80. Much of the difference in appearance between the two patterns is the result of the different viewing angles. The surface scrubbing profiles are actually very similar. Nozzle exit velocity has only a small effect on spreading so long as the flow remains attached. Therefore,

for geometrically similar configurations, the scrubbed surface patterns are expected to be geometrically similar.

3.3.4.2 Mean Velocity Profiles - Two comparisons of nondimensional velocity profiles are shown in Figure 3-81. These are midspan profiles at the trailing edges of similar configurations with the AR-4 and AR-8 nozzles on both the large-scale and small-scale models. The ordinate is normalized to the location in the outer mixing region where the velocity is half the peak value. The abscissa is normalized to the peak velocity.

It may be seen in Figure 3-81 that this process of normalization gives a good collapse of the data. A common curve would fit the outer profile fairly well with either nozzle of either size. The inner profiles for similar nozzles agree somewhat, but differ with nozzle aspect ratio. The fit in the outer region is expected because the flow mixing in the region is fairly well developed and because fully developed mixing profiles are similar. The mixing in the inner region is just beginning, so no universal profile can be expected.

3.3.4.3 Turbulence Profiles - Turbulence intensity profiles are not expected to scale well because turbulence is a much stronger function of initial turbulence levels than is mean velocity. The example (Figure 3-82), however, shows good agreement between the turbulence intensity profiles when distance is normalized using the same half-velocity location that was used with the mean velocities. The good agreement is assumed to be fortuitous.

3.3.5 Summary of Effects of Geometric Variables on Peak Velocity

It is believed that practical considerations such as internal losses and structural compatibility ultimately will require nozzles of low aspect ratio, say less than four. This results in a jet-dimension-to-flow-path-length ratio which is short in terms of flow field development. More importantly, the inner profile at the trailing edge is in the initial stage of transition from a boundary layer profile before the edge to a jet mixing profile some distance into the wake region. Similarity profiles are therefore not expected. However, the peak values of mean velocity should vary consistently with the major geometric and operational variables.

The peak velocity and the turbulence intensity value at the knee of the turbulence profile were examined at the trailing edge in the midspan plane for attached flow cases. Knee turbulence is used because the peak value, particularly for longer flow lengths, often occurs far from the edge and far from the high-shear area where the noise source is presumed to be. Figure 3-83(A) shows how peak velocity and knee turbulence vary with the nozzle installation variables. The measured values were found to be well behaved with respect to the chosen variables. Peak velocity decreases as impingement angle increases and increases as the nozzle is moved aft while maintaining a constant flow length. The first tendency is believed to be the result of jet spreading, which increases the effective length-to-diameter ratio of the jet flow. The reason for the increase in velocity with nozzle chordwise position is not clear, although it might be related to the partial development of the flow before the flap is reached.

The effects of flap variables on peak velocity are shown in Figure 3-83(B). The peak velocity decreases with increasing flap deflection, flap radius,

and flow length. Only the relatively small decrease with increasing flap radius is surprising. The intuitive thought prior to testing had been that, other things being equal, peak velocity would decrease with decreasing radius of curvature because of the higher radial acceleration of the flow and its greater tendency to separate.

Sensitivity factors for the effects of δ_f , θ_N , and L_f/R_c on the ratio U_p/U_j were derived by fitting curves through the data points of Figure 3-83. The resultant expressions, given below, may be used to correct peak velocity measurements to a reference configuration in which $\delta_f = 60^\circ$, $\theta_N = 20^\circ$, and $L_f/R_c = 2.86$.

$$C_{\delta_f} = 2.21 \left(\frac{\delta_f}{60^\circ} \right)^{-0.095 - 1.21}$$

$$C_{\theta_N} = -0.131 \left(\frac{\theta_N}{20^\circ} \right) + 1.128$$

$$C_{R_c/L_f} = 0.966 \left(\frac{L_f/R_c}{2.86} \right)^{-0.12 + 0.039}$$

Data from a given configuration are divided by the appropriate C's to correct them to the reference configuration.

Jet velocity profiles are expected to be functions of a length-to-diameter ratio. Length is usually measured from the nozzle exit along the jet axis. In USB configurations where the jet follows a curved surface, flow length along the surface from the nozzle to the trailing edge is an appropriate length variable. Hydraulic diameter, defined as $D_H = 4 A_N/P_N$, is used for the diameter term. This parameter relates the momentum of the jet ($\rho A_N V_j$) to the surface area available for momentum exchange with the environment ($P_N L_f$). It was reasoned that D_H was inappropriate for USB configurations because it fails to account for the reduction in mixing area caused by the

presence of the wing/flap surface. A modified hydraulic diameter, $D_H' = 4A_N / (P_N - W)$, was used as a first approximation to account for the entrainment blockage caused by the wing.

Figure 3-84 shows the results of using the previously defined sensitivity factors and modified hydraulic diameter to collapse the peak velocities measured at the trailing edges of a wide range of configurations. Only configurations having well attached flow as evidenced by flow visualizations and by relatively well defined peak velocity profiles are included.

3.4 TURBULENT VELOCITY CHARACTERISTICS

Turbulence generation and propagation in the vicinity of the trailing edge are believed to be the dominant source of USB flyover noise. Measurements of fluctuating velocity characteristics were therefore concentrated in that region. Product-moment correlations and some narrow-band spectra were obtained.

3.4.1 Correlations

Correlation functions were obtained for two configurations: a tight-radius short-flap configuration and a more representative configuration. Both configurations employed the AR-8 nozzle at 20% chord with a 20° impingement angle.

Linearized hot-wire anemometers and an on-line digital correlator were used to obtain the autocorrelations and the two-point space/time correlations. Single-wire probes were used for all measurements.

3.4.1.1 Severe Configuration - A small number of correlation measurements were made with a configuration distinguished by relatively severe geometry: 60° flap deflection with a 5.08-cm radius of curvature and a 3.81-cm flat trailing edge.

Figure 3-85 presents the results of a series of autocorrelations made in the midspan plane at 0.20, 1.27, 2.54, and 5.08 cm downstream of the trailing edge and at nine evenly spaced distances from 0 to 5.08 cm above the wing. The hot-wire was parallel to the trailing edge. The peak autocorrelations were cross-plotted against distance above the wing to obtain Figure 3-86. The following observations can be made:

- o Near the wing surface in the newly developing mixing region, turbulence rapidly builds to a peak level which slowly decays with distance downstream.
- o Turbulence levels in the outer region of the flow decay with downstream distance; peak levels were reached upstream of the trailing edge in the early stages of mixing.

3.4.1.2 Representative Configuration - More extensive correlation measurements were made in the wake region of the representative configuration which employed a 7.62-cm radius flap with a 6.47-cm flat trailing edge.

Longitudinal Autocorrelations - Streamwise growth and decay of the autocorrelations were surveyed along a line 0.1 cm above the wing surface in the midspan plane. The 0.1-cm distance above the surface was selected on the basis of trailing edge turbulence, which shows maximum intensity at that location. The peak autocorrelation at $Z=0.1$ cm occurs between 0.76 and 2.54 cm downstream of the trailing edge.

Space/Time Correlations - Longitudinal, lateral, and transverse two-point space/time correlations are shown in Figures 3-87 through 3-89. The longitudinal and transverse correlations were made with single-wire probes parallel to the trailing edge; the downstream and upper wires, respectively, were movable. The lateral correlations were made with single-wire probes normal to the upper surface of the trailing edge segment; the outer wire was movable. In all cases the signal from the fixed wire was delayed relative to that from the movable wire.

Longitudinal correlations were made in the midspan plane along a line 0.1 cm above the upper surface of the trailing edge. Fixed wire locations of 0.76, 1.59, and 2.54 cm aft of the trailing edge were used with wire separation distances of up to 3 cm. These correlations are shown in Figure 3-85 and are discussed later.

Lateral correlations were made along a line parallel to the trailing edge and through a point 1.59 cm after and 0.1 cm above the surface. Separation distances of up to 0.5 cm were used. The correlations are shown in Figure

3-88. The lack of peaks at non-zero time delays is characteristic of spanwise space/time correlations. Similar correlation functions are obtained when the outboard signal is delayed. The decay of the maximum correlation with increasing separation is very rapid.

Transverse space/time correlations were made along a line normal to the upper surface of the trailing edge segment and passing through a point 1.59 cm downstream of and 0.1 cm above the surface. These correlations, shown in Figure 3-89, cover a separation distance of 0.8 cm. The shapes of the correlation functions and the rapidly decaying maximum correlation are similar to those seen in the lateral correlations.

Turbulence Parameters - Convection velocity, length scales, and time scales were derived from the correlations described above. Figure 3-90 shows the separation distance between the hot-wires versus the delay time to the corresponding peak correlations. The slope of the line through the points is taken to be the convection velocity. The lines shown in Figure 3-90 for fixed wires at 0.76, 1.59, and 2.54 cm after the trailing edge yield convection velocities of 63.2, 57.4, and 62.6 m/sec respectively. The corresponding jet velocity is 126.2 m/sec, resulting in ratios of convection velocity to jet velocity of 0.50, 0.45, and 0.50.

The integral length scale of turbulence is a length characteristic of the turbulence structure. It is defined as the integral under the curve of the zero-time-delay space/time correlation plotted against separation distance. The zero-time-delay correlations for the longitudinal and transverse directions are given in Figure 3-91. The areas under curves, over the ranges shown, yield length scales of 0.873 cm and 0.305 cm in the longitudinal and transverse directions respectively. The ratio of these

length scales, 2.86, is defined to be the scale of anisotropy. The time scale, defined as the ratio of the longitudinal length scale to the convection velocity, is 152 microseconds. The significance of these turbulence characteristics is discussed in the analysis report.

3.4.2 Narrow-Band Spectra for Representative Configurations

Narrow-band spectra were obtained at various locations in the wake region of the representative configuration. A single-wire probe was used with a hot-wire anemometer and a 50-Hz bandwidth tracking filter. The hot-wire paralleled the trailing edge. The results are shown in Figure 3-92 as turbulence intensity in a 50-Hz band vs center frequency, with the intensity normalized to the value at the low-frequency end of the spectrum. Generally the spectra are flat below some frequency and fall off at about 6 dB per octave thereafter. The location of the knee depends on the position of the measuring point.

3.4.2.1 Effect of Longitudinal Position - Figure 3-92(A) shows how the spectrum varies along the midspan plane. The low-frequency content of the spectrum increases with distance downstream of the trailing edge as the high-frequency turbulence generated on the early part of the newly-established mixing region dies out.

3.4.2.2 Effect of Lateral Position - Turbulence spectra are affected in the same way by lateral position in several different regions of the wake. Figure 3-92 includes spectra near the trailing edge, well above the surface, and well after the trailing edge. The two sets of spectra in the inner mixing region, Figure 3-92(B) and (C), are of the typical shape and show the lipline spectra to be more dominated by the low frequencies than are the

midspan spectra. In the outer mixing region, Figure 3-92(D), the midspan spectrum falls off faster and the lip line spectrum is wavier than the typical spectrum. The high content of low-frequency components is typical of developed mixing regions. A possible reason for the atypical shapes is the relatively low velocities at the measurement locations.

3.4.2.3 Effect of Transverse Position - Figure 3-92(E) shows a shift toward lower-frequency turbulence with increasing distance above the surface. The direction of movement is from newer to older regions of mixing, so this is consistent with the previous observation. Near the trailing edge high frequencies tend to prevail near the plane of the upper surface. Farther into the wake the dominant high-frequency location is a little farther above the surface, as may be seen by comparing Figures 3-92(E) and 3-92(F).

3.5 PERFORMANCE

3.5.1 Static Performance

Lift and drag forces on the wing and flap at zero forward speed were measured on the outdoor test rig (all nozzles except AR-2) and in the anechoic wind tunnel as part of the forward speed effects tests (AR-2 nozzle). In both tests the nozzle was mounted separately from the wing/flap assembly, which was supported on a balance. The measured lift and drag forces were converted to jet turning angle and turning efficiency. Angle and efficiency are plotted in polar coordinates in Figures 3-93 for the basic configurations and in rectangular coordinates in Figure 3-94 for the flap trailing edge modifications. Each point represents the average over all jet velocities, as jet velocity had a negligible effect on both angle and efficiency.

3.5.1.1 Effect of Nozzle Shape - Figure 3-93 shows that with 30° flaps the QCSEE nozzle has the best performance, with efficiencies of 0.95 or better and turning angles exceeding 25° with the doors open. The performance of the circular nozzle is almost as good when directly on the wing but is 10% lower in efficiency when mounted off the wing. The turning angles achieved with the AR-4 and AR-8 nozzles are relatively low (13 - 19°).

The static runs of the anechoic wind tunnel (AWT) test of the AR-2 nozzle with 30° flaps show a turning angle of 35° . The actual turning angle, however, cannot exceed the flap angle. The discrepancy is probably due to the fact that the nozzle was rigidly attached to the air supply line in the AWT tests. Thus the jet flow direction at the nozzle exit could not be determined from nozzle load cell readings, as was done in the other tests. The nozzle exit flow direction in the AWT tests had to be estimated from the outdoor data and may therefore be inaccurately accounted for in the turning angle and turning efficiency equations. The wing deflected the effective nozzle exit flow by 8° in the outdoor tests of the AR-4 and AR-8 nozzles at a nominal impingement angle of 20° . A deflection of 8° was therefore used in reducing the AR-2/ 20° -impingement data from the AWT to turning angle and efficiency. Deflection of 10° or more by the wing would be required to make the calculated turning angle less than the flap angle of 30° .

The QCSEE nozzle with a 10° impingement angle also shows anomalous results in Figure 3-93 — a turning efficiency of 1.04 and a turning angle of 32° with 30° flaps. These discrepancies are unexplained. With 60° flaps the AR-4 and AR-8 nozzles are low in both angle (36° - 40°) and efficiency (less than 0.70). The circular nozzle is considerably better, especially when spaced off the wing. The AR-2 nozzle, at 53° turning angle and 0.90 efficiency, shows the best performance of all, although these values come from the AWT test and thus are questionable for the reasons discussed above.

3.5.1.2 Effects of Nozzle Position - The effects of nozzle translation and rotation were investigated with the AR-4 nozzle (Figure 3-93). Aft movement is seen to increase efficiency (at the expense of increased noise). Varying impingement angle from the basic 20° reduces either turning angle (with flatter impingement) or efficiency (with steeper impingement).

3.5.1.3 Effects of Flap Treatment - The effects of applying various treatments to the flap were investigated on the outdoor rig with the AR-8 nozzle at 20% chord with 20° impingement and 30° flaps. The treatments, defined schematically in Figure 2-24, consisted primarily of using felt metal or perforated sheet as the upper surface of the whole flap, the upper surface of the trailing edge, and/or the single surface of a short trailing edge extension. The lower surface was a solid sheet in each case, and there was no filler material between the surfaces. The splitters of treatment 16 were similar to vortex generators except that they were aligned with the wing chord.

Figure 3-94 shows the effects of these modifications on turning angle and efficiency. The basic solid flap (treatment 1) had the highest efficiency, by 0.7%, and its turning angle was within 1.3° of the best. The trailing edge splitters (treatment 16) gave almost as good an efficiency and a 1° higher turning angle. The largest changes were induced by covering the whole flap with treatment material (treatments 2, 3, 4, and 13); turning efficiency decreased by 7-11% and turning angle decreased by as much as 4° . The increased surface roughness increases friction and also thickens the boundary layer, raising the jet off the surface and reducing the turning angle. Treating only the trailing edge (treatments 5, 6, and 7) reduced the efficiency loss in about the same proportion as the reduction in treated area.

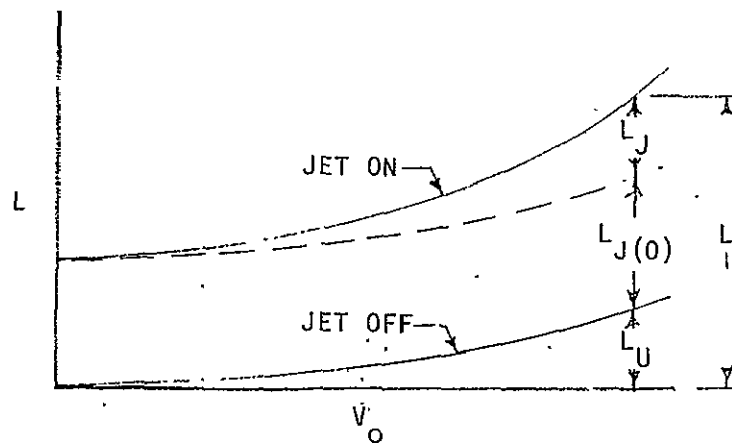
The trailing edge extensions (treatments 8-14) also reduced the turning angle in most cases; the effect ranged from 1° more turning to 4° less. Treated extensions on the untreated flap (treatments 8-12) reduced efficiency by about 0.02. Combining treated extensions with trailing edge treatment (14) or whole flap treatment (13) substantially increased the efficiency degradation.

3.5.2 Effect of Forward Speed

Figure 3-95 shows how the lift and drag of the two wing/flap combinations tested in the anechoic wind tunnel vary with forward speed and jet velocity. The nozzle was non-metric in these tests. The forces plotted in Figure 3-95 can be treated as the sum of three components -

L_U	D_U	Unblown lift (drag)
$L_{J(0)}$	$D_{J(0)}$	Static lift (drag) due to jet
L_J	D_J	Forward speed lift (drag) due to jet

The following sketch, in the format of Figure 3-95, shows the three components. (Lift is used as the example from here on. The drag relationships are analogous in all respects.)



The components can be expressed as coefficients of freestream dynamic pressure and nozzle thrust as follows:

Unblown Lift - In the usual way, $L_U = C_L q_0 S$, where C_L is the lift coefficient with the jet off, q_0 is the freestream dynamic pressure ($\frac{1}{2} \rho_0 V_0^2$), and S is the wing area. The lift and drag coefficients from the present tests are:

	C_L	C_D
30° Flaps	0.79	0.13
60° Flaps	1.06	0.30

Doubling the flap deflection from 30° to 60° increases C_L by one-third and more than doubles C_D .

Static Lift Due to Jet - The static forces on the wing are directly proportional to nozzle thrust F_g ; thus $L_{J(o)} = (L_{J(o)}/F_g) F_g$. The wing-force-to-thrust ratios from the static runs in the anechoic wind tunnel are:

	$L_{J(o)}/F_g$	$D_{J(o)}/F_g$
30° Flaps	0.246	0.326
60° Flaps	0.510	0.439

(These ratios were used to calculate static turning angle and turning efficiency, discussed in the previous section.) Static blowing produces more drag than lift with 30° flaps and more lift than drag with 60° flaps.

Forward Speed Lift Due to Jet - This component reduces to a lift coefficient increment, ΔC_{L_J} , which is the change in lift coefficient caused by the jet. Thus $L_J = \Delta C_{L_J} q_0 S$. The increments obtained in the present test are plotted against thrust coefficient $C_T (= F_g / q_0 S)$ in Figure 3-96. The points are from

the faired curves of Figure 3-95. The increments for each configuration are single-valued functions of C_T . As in the static case, blowing causes more lift increase on the 60° flaps than on the 30° flaps over the whole C_T range. The drag increments are lower than the lift increments at both flap settings; this is in contrast to the static effect where blowing causes more drag than lift with the 30° flaps.

A. NOZZLE EFFECTS - REPRESENTATIVE FLAP

θ_N	$\frac{X_N}{C}$	20%		50%	
		SEPARATED	ATTACHED	SEPARATED	ATTACHED
0		AR-8, AR-2, Circle D, Ellipse	AR-4*, QCSEE*	AR-2, Circle, QCSEE	
2				Ellipse	
5					D
10			AR-8, AR-4, Circle, QCSEE, D, Ellipse	Circle, Ellipse	AR-2*, QCSEE*, D
15					
20			AR-8, AR-2, Circle, Ellipse, D		AR-2, Circle, QCSEE, D, Ellipse
$R_C = 7.62 \text{ CM}$, $\delta_f = 60^\circ$, $L_{TE} = 3.81 \text{ CM}$, $NPR = 1.55$					

B. NOZZLE EFFECTS - SHORT RADIUS FLAP

θ_N	$\frac{X_N}{C}$	20%		50%	
		SEPARATED	ATTACHED	SEPARATED	ATTACHED
0		AR-4*, AR-2			
10			AR-4, AR-2		AR-2
15			AR-4		
20			AR-4, AR-2		AR-2
30			AR-4		
$R_C = 5.08 \text{ CM}$, $\delta_f = 60^\circ$, $L_{TE} = 6.47 \text{ CM}$, $NPR = 1.55$					

C. NPR EFFECTS vs. θ_N

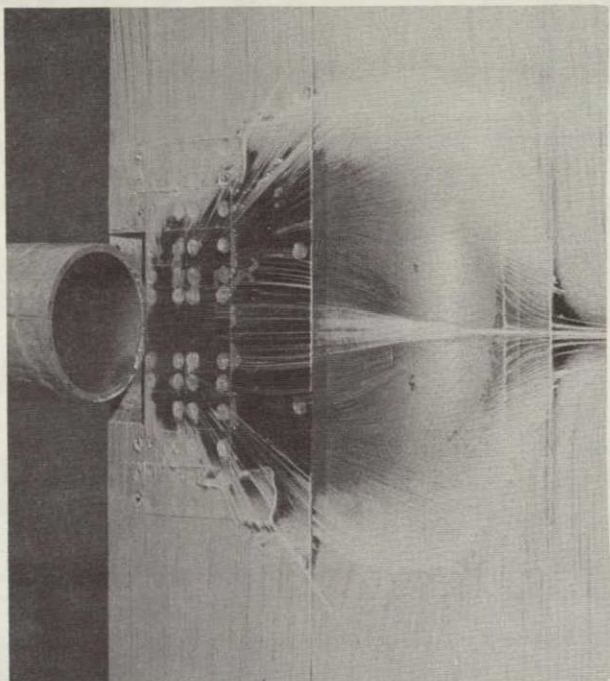
NPR	$\frac{X_N}{C}$	20%		50%	
		SEPARATED	ATTACHED	SEPARATED	ATTACHED
1.1				0°, 5°, 10°	15°, 30°
1.3			0°		
1.35			0°		0°, 10°, 20°
1.45			0°		0°, 10°, 20°, 30°
1.55					
AR-4, $R_C = 7.62 \text{ CM}$, $\delta_f = 60^\circ$, $L_{TE} = 3.81 \text{ CM}$					

*INDICATES UNCERTAINTY

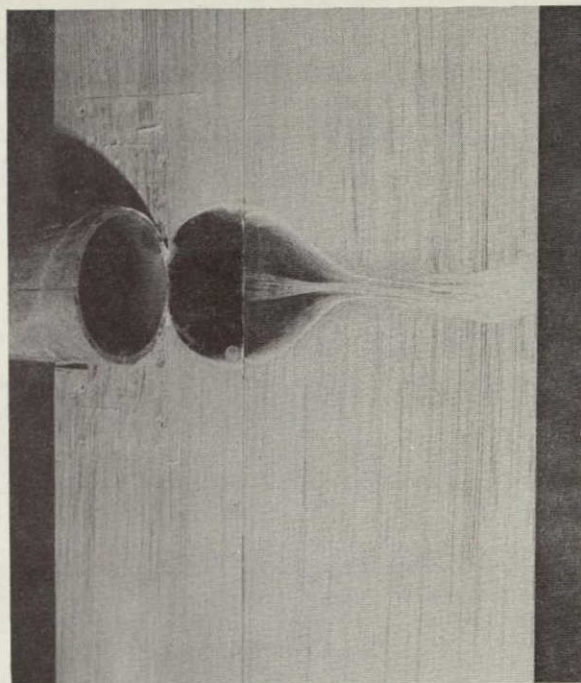
TABLE 3-1. FLOW ATTACHMENT OBSERVATIONS USING OIL FLOW

NOZZLE	RUN	$\delta f \sim^\circ$	$\theta_N \sim^\circ$	U_j	NOZZLE	RUN	$\delta f \sim^\circ$	$\theta_N \sim^\circ$	U_j
AR-4	39	30	10	562.5	AR-8	1	30	10	639.6
	40			689.7		2			732.8
	41			807.9		3			843.3
	42			943.6		4			971.4
	32		20	570.0		5		20	637.3
	31			699.8		6			746.7
	30			844.4		7			859.7
	29			975.1		8			980.5
	21		30	604.0		17		30	669.1
	22			735.9		18			773.0
	23			874.9		19			895.5
	24			995.2		20			998.0
	63	60	10	577.7		111	60	10	389.5
	64			709.1		112			585.7
	65			841.4		113			717.1
	66			980.9		114			863.8
	79		20	576.6		115		20	986.2
	80			699.2		97			388.8
	81			821.9		98			568.8
	82			959.1		99			695.5
	83		30	570.3		100		30	832.7
	84			710.8		101			982.8
	85			864.9		93			592.7
	86			985.7		94			741.5
						95			872.8
						96			1002.0

TABLE 3-2. LARGE MODEL VELOCITY PROFILE RUNS

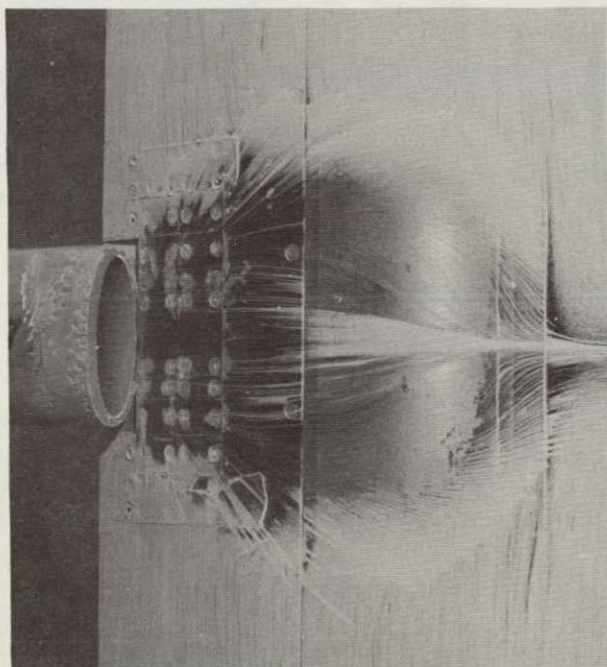


$$X_N = 0.20C$$

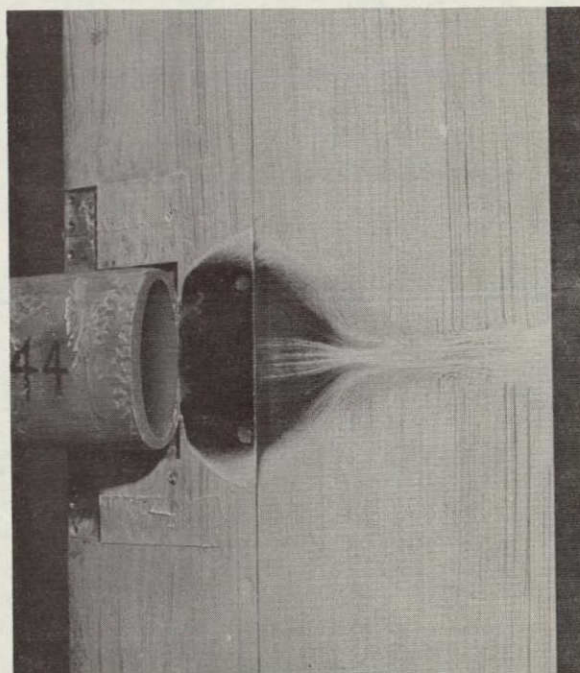


$$X_N = 0.50C$$

(A) CIRCULAR NOZZLE - 5.08 CM DIA.



$$X_N = 0.20C$$

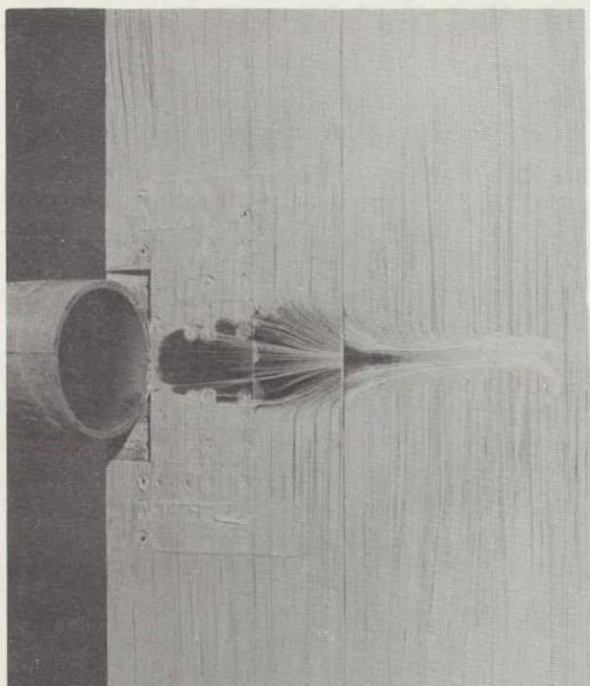


$$X_N = 0.50C$$

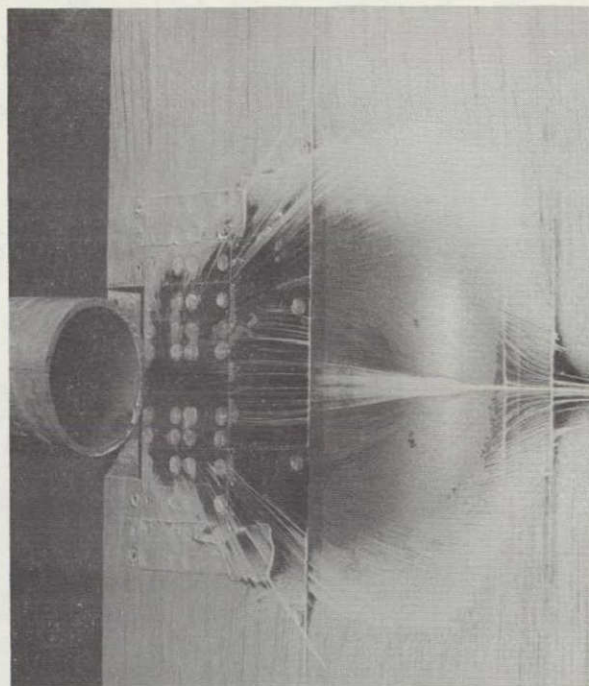
(B) ELLIPTICAL NOZZLE, 5.74CM WIDE, 2.25CM HIGH.

FIGURE 3-1. EFFECT OF NOZZLE CHORDWISE LOCATION ON FLOW ATTACHMENT;
 $\theta_N = 10^\circ$, $R_c = 7.62$ CM, $\delta_f = 60^\circ$, $NPR = 1.55$.

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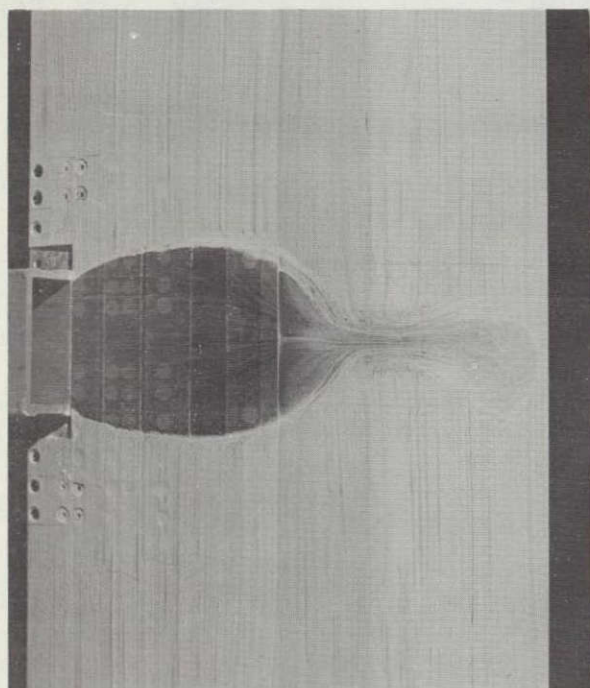


$\theta_N = 0^\circ$

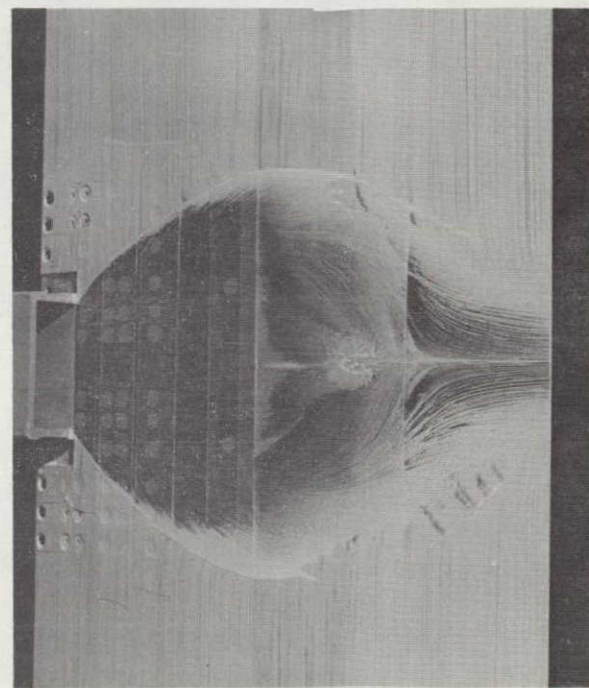


$\theta_N = 10^\circ$

(A) CIRCULAR NOZZLE - 5.08 CM DIA.
 $R_C = 7.62$ CM



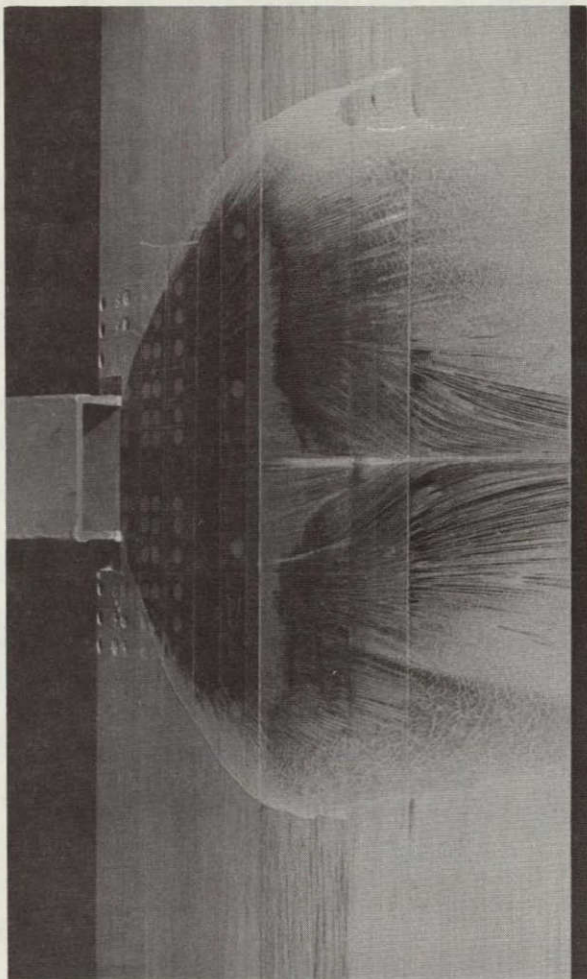
$\theta_N = 0^\circ$



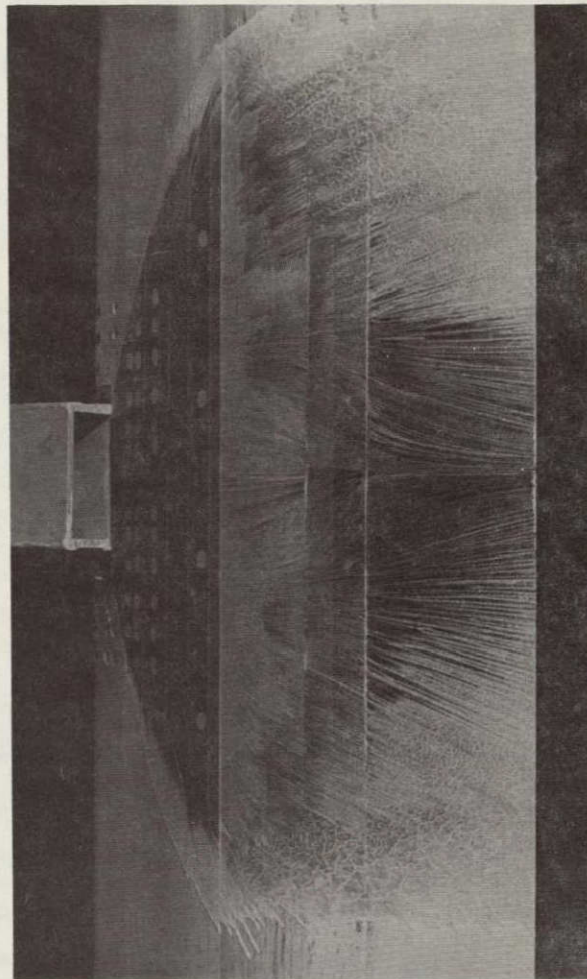
$\theta_N = 10^\circ$

(B) AR-2 NOZZLE, $R_C = 5.08$ CM

FIGURE 3-2. EFFECT OF FLOW IMPINGEMENT
 ANGLE ON FLOW ATTACHMENT;
 $X_N = 0.20C$, $\delta_f = 60^\circ$, $NPR = 1.55$.



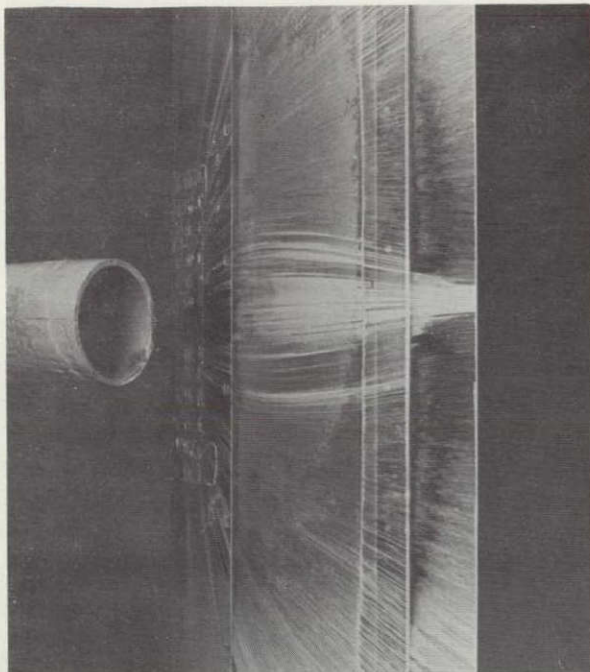
$$\theta_N = 20^\circ$$



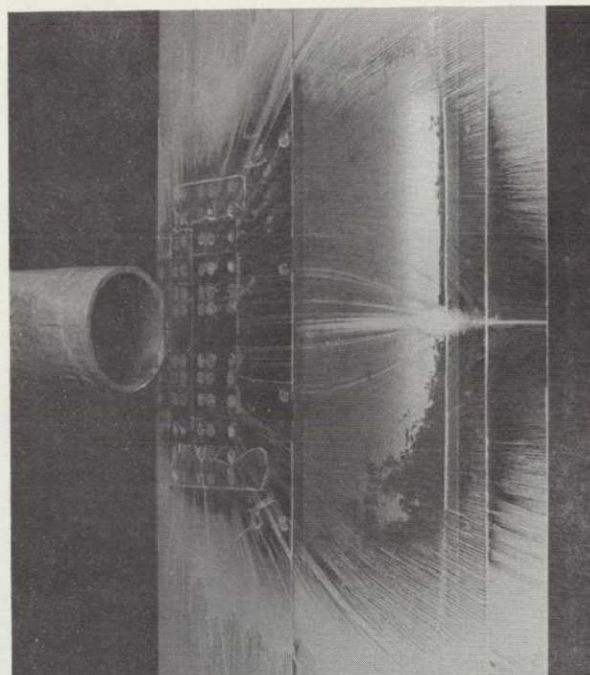
$$\theta_N = 30^\circ$$

(C) AR-2 NOZZLE, $R_C = 5.08$ CM

FIGURE 3-2. CONCLUDED.

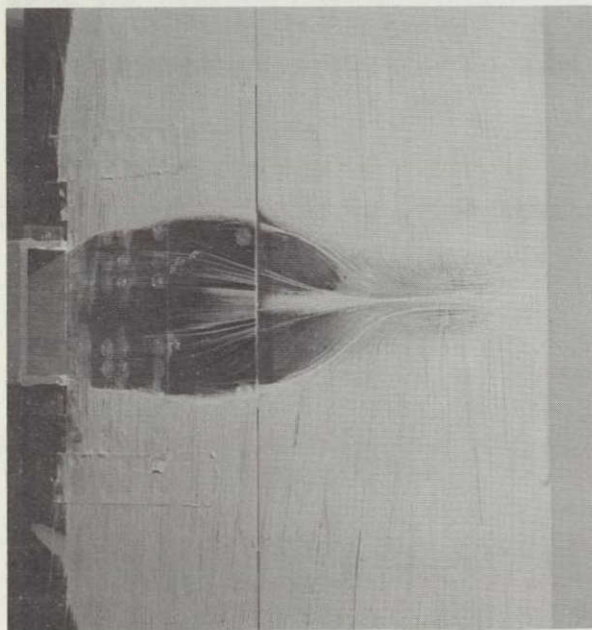


$\theta_N = 40^\circ$; NOZZLE/
WING GAP = 1.59 CM

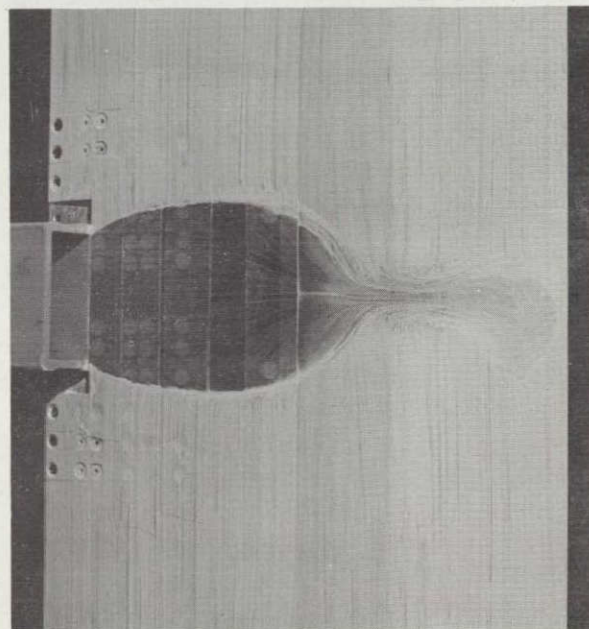


$\theta_N = 20^\circ$; NOZZLE/
WING GAP = .32 CM

FIGURE 3-3. EFFECT OF VECTORED THRUST
ON FLOW ATTACHMENT; CIRCULAR
NOZZLE - 5.08 CM DIA., $X_N = 0.20C$,
 $R_C = 7.62$ CM, NPR = 1.55.

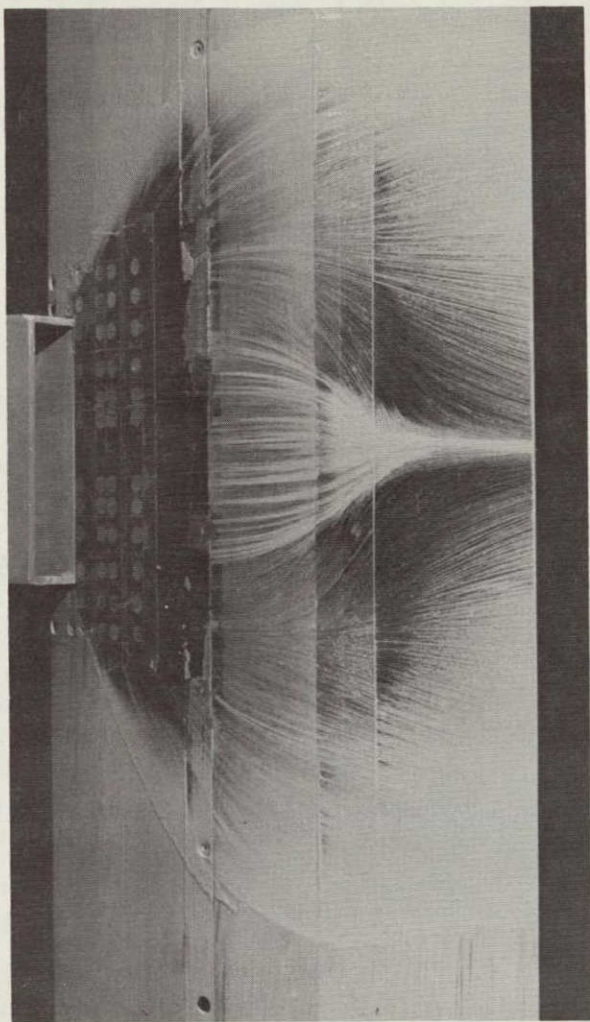


$R_C = 7.26$ CM

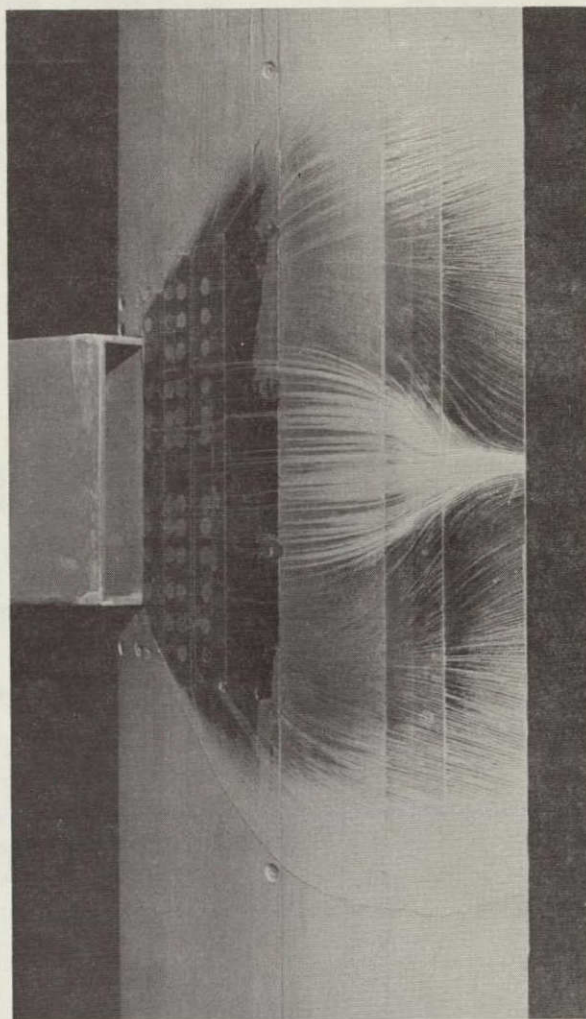


$R_C = 5.08$ CM

FIGURE 3-4. EFFECT OF FLAP RADIUS ON
FLOW ATTACHMENT; AR-2 NOZZLE,
 $X_N = 0.20 C$, $\theta_N = 0^\circ$, $\delta_f = 60^\circ$, NPR = 1.55,
 $L_{te} = 6.47$ CM.

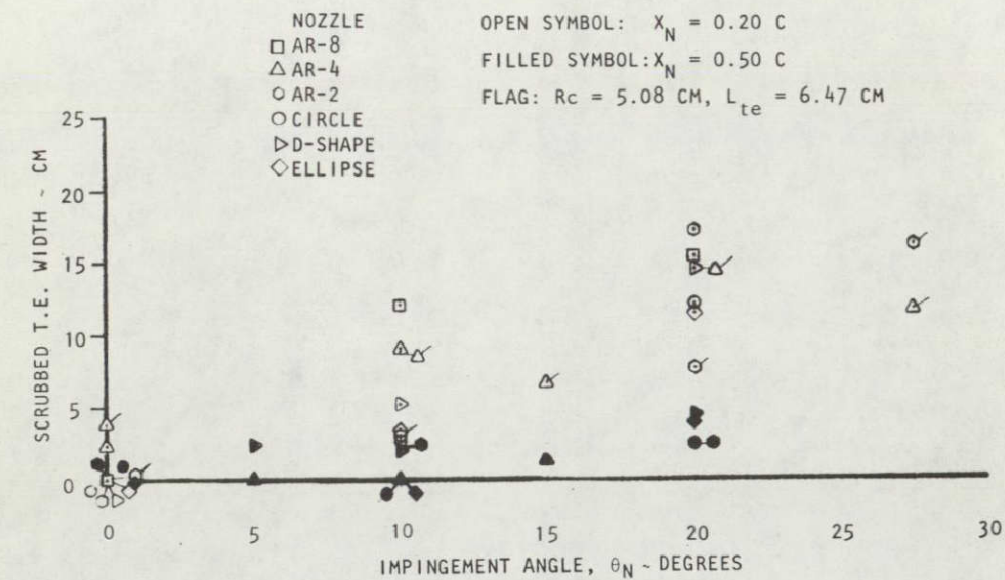


$L_{te} = 6.47 \text{ CM}$

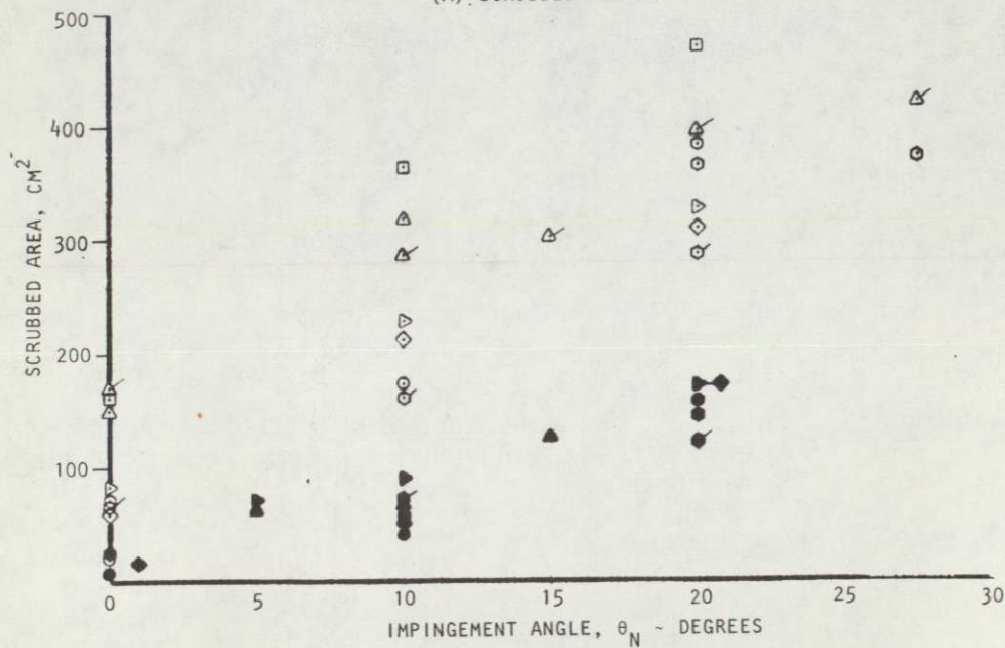


$L_{te} = 3.81 \text{ CM}$

FIGURE 3-5. EFFECT OF TRAILING EDGE LENGTH ON FLOW ATTACHMENT.
 AR-4 NOZZLE, $x_N = 0.20 \text{ CM}$, $\theta_N = 20^\circ$, $R_C = 5.08 \text{ CM}$,
 $NPR = 1.55$.



(A) SCRUBBED WIDTH.



(B) SCRUBBED AREA.

FIGURE 3-6. CONFIGURATION EFFECTS ON FLOW SPREADING.
 $\delta_f = 60^\circ$; $R_c = 7.62 \text{ CM}$; $L_{te} = 3.81 \text{ CM}$; $\text{NPR} = 1.55$.

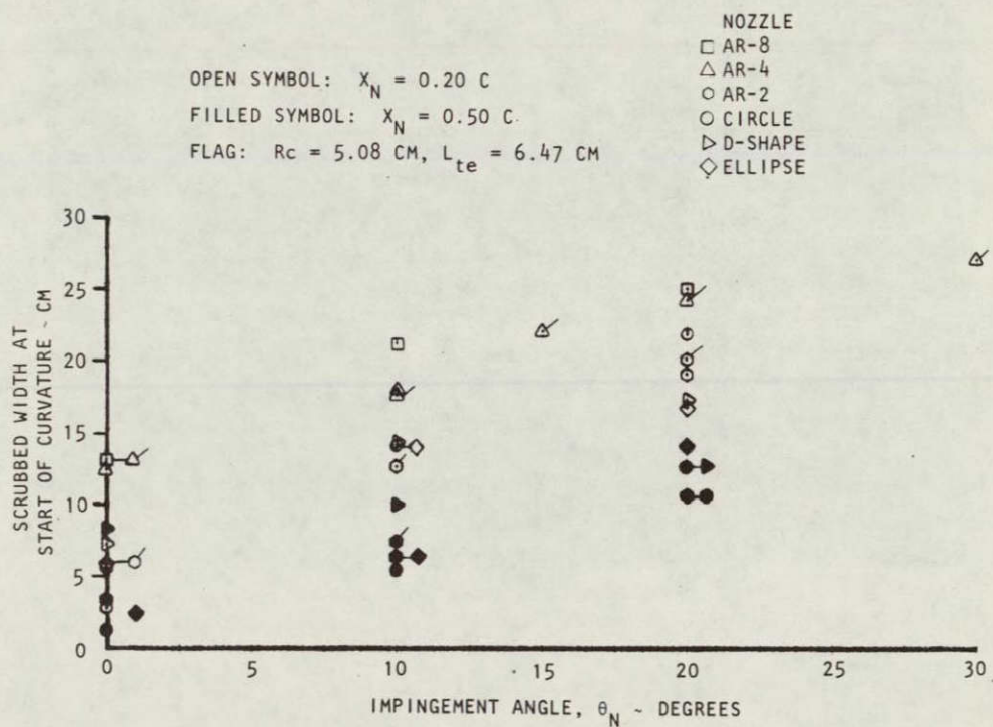


FIGURE 3-7. SCRUBBED WIDTH AT THE START OF CURVATURE; $\delta_f = 60^\circ$, $R_c = 7.62 \text{ CM}$, $L_{te} = 3.81 \text{ CM}$, $\text{NPR} = 1.55$

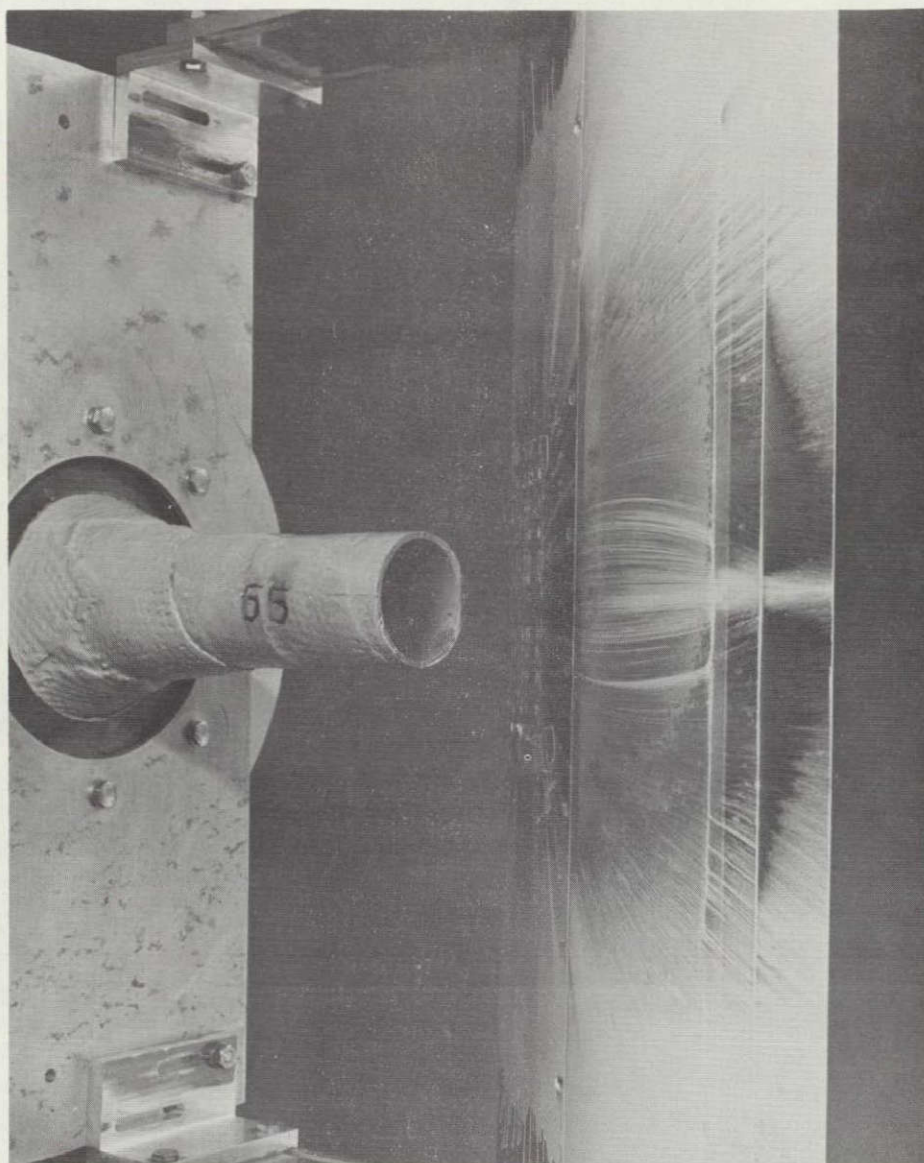
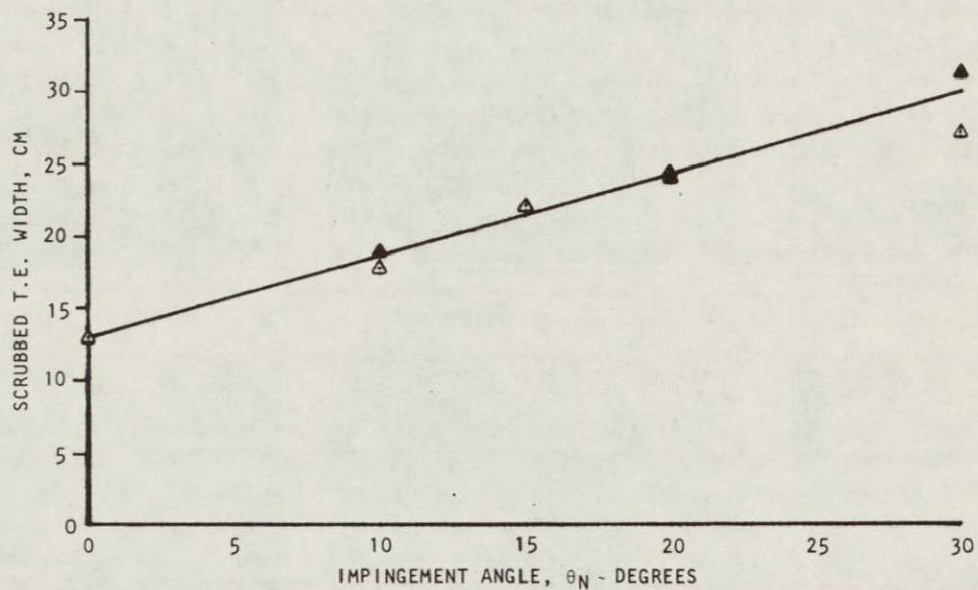
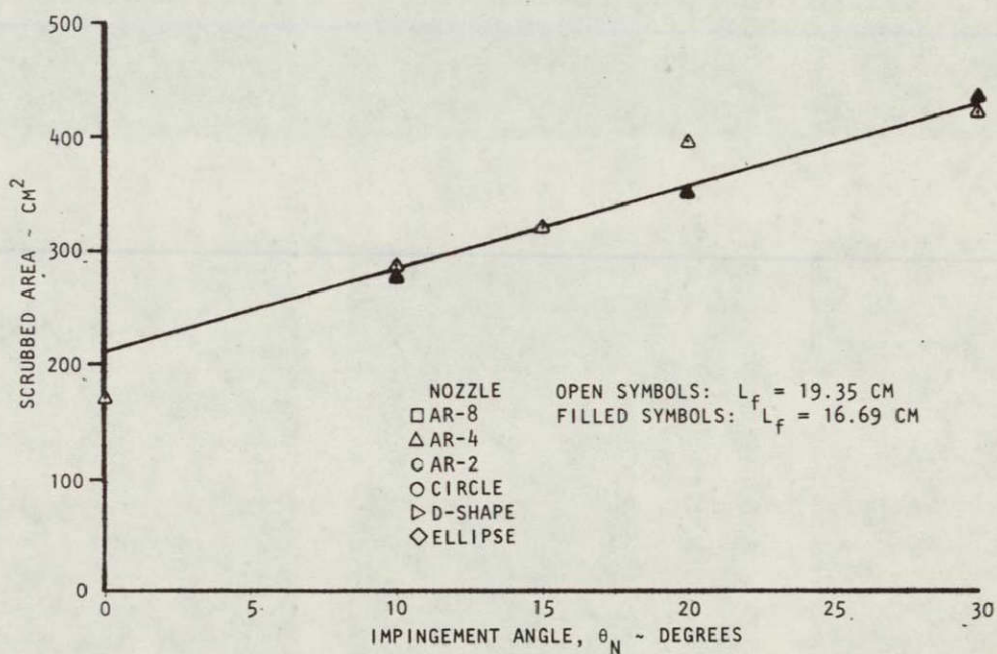


FIGURE 3-8. EFFECT OF VECTORED THRUST; CIRCULAR NOZZLE -
5.08 cm DIA. $X_N = 0.35$ c, $Z_N = 3.3$ cm,
 $\theta_N = 40^\circ$, NPR = 1.55, $R_C = 7.62$ cm, $\delta_f = 60^\circ$,
 $L_{te} = 3.81$ cm



(A) SCRUBBED WIDTH.



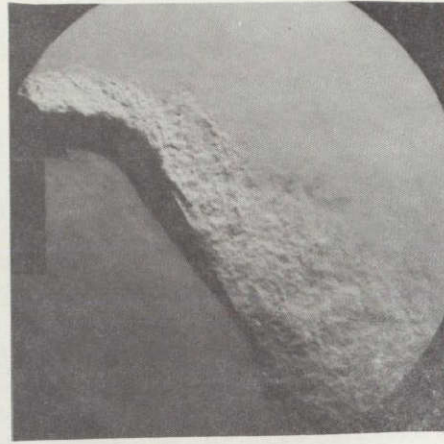
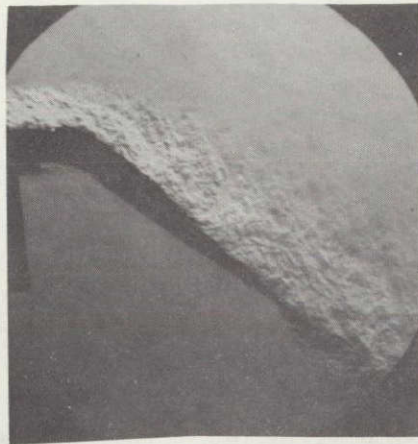
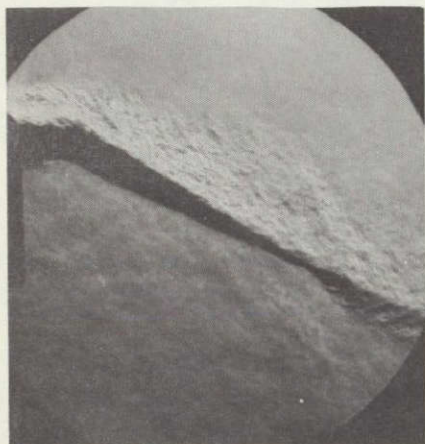
(B) SCRUBBED AREA.

FIGURE 3-9. EFFECT OF FLOW LENGTH ON FLOW SPREADING; AR-4 NOZZLE, $X_N=0.20C$, $R=5.08\text{CM}$, $\delta_f=60^\circ$, $\text{NPR}=1.55$

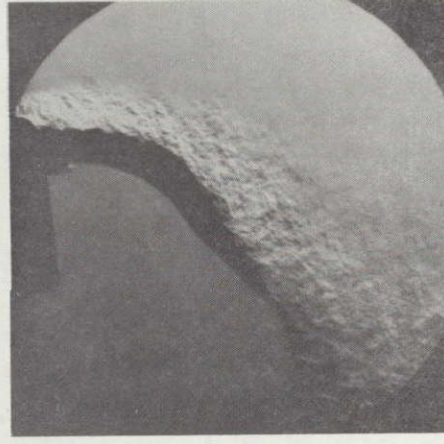
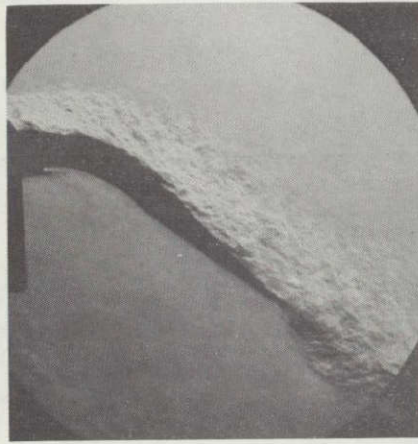
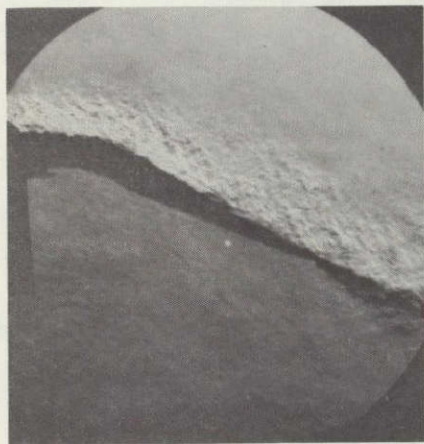
$$\delta_f = 30^\circ$$

$$\delta_f = 45^\circ$$

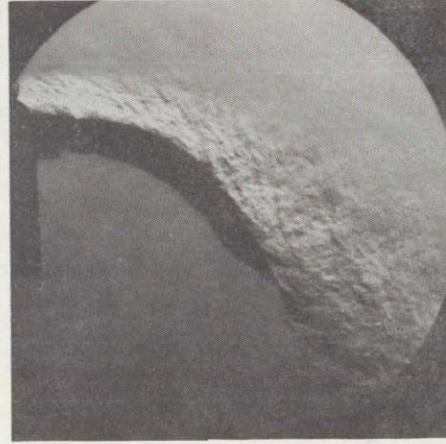
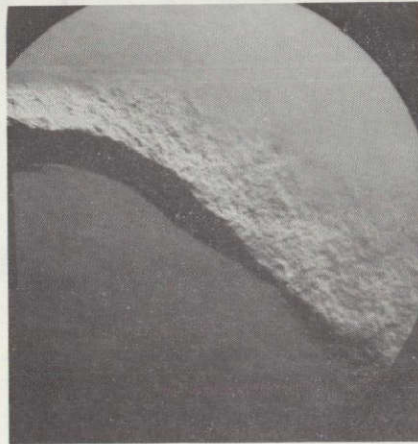
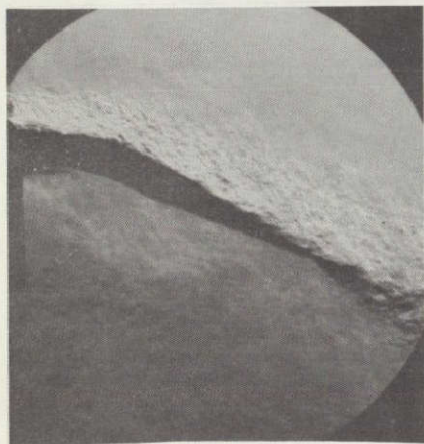
$$\delta_f = 60^\circ$$



(A) $R_c = 5.08 \text{ CM}$



(B) $R_c = 7.62 \text{ CM}$



(C) $R_c = 10.16 \text{ CM}$

FIGURE 3-10. EFFECTS OF FLAP RADIUS AND DEFLECTION BY SPANWISE SCHLIEREN PHOTOGRAPHY; AR-8 NOZZLE, $X_N = 0.20C$, $\theta_N = 30^\circ$, $NPR = 1.47$, $L_f = 21.77 \text{ CM}$

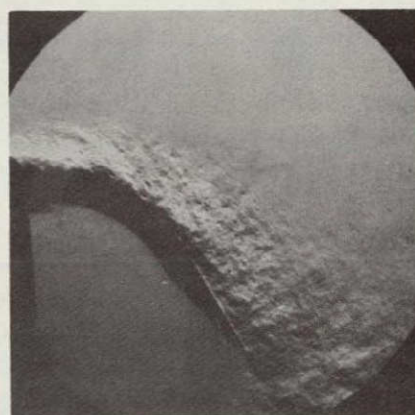


$\theta_N = 0^\circ$

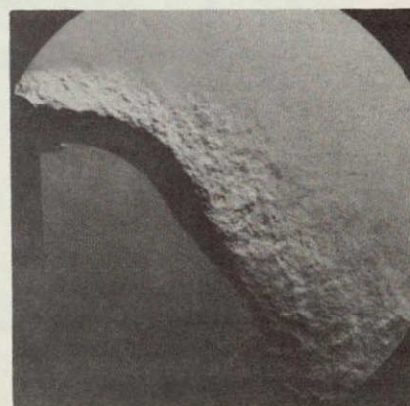
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$\theta_N = 5^\circ$



$\theta_N = 10^\circ$



$\theta_N = 20^\circ$

FIGURE 3-11. EFFECT OF IMPINGEMENT ANGLE
BY SPANWISE SCHLIEREN PHOTOGRAPHY;
AR-8 NOZZLE $X_N = 0.20C$, $R_c = 7.62\text{CM}$,
 $\delta_f = 60^\circ$, $\text{NPR} = 1.47$, $L_f = 21.77\text{CM}$

$$L_{te} = 3.81 \text{ CM}$$

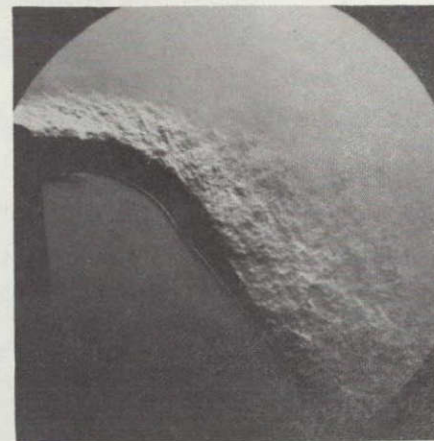
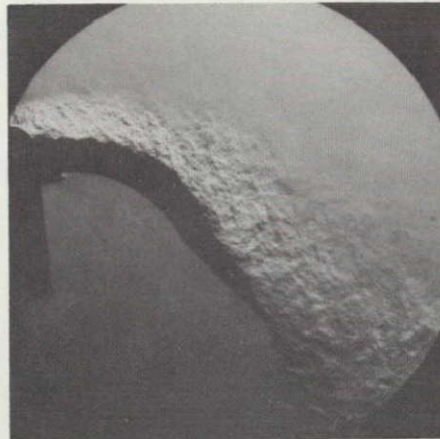
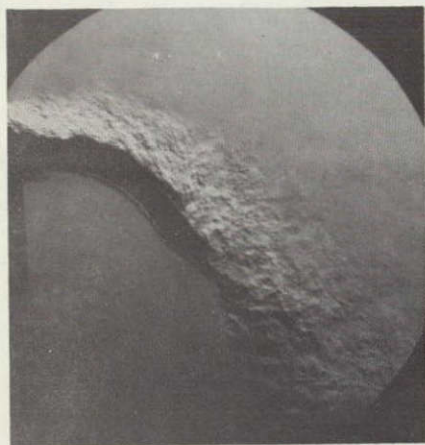
$$L_f = 19.11 \text{ CM}$$

$$L_{te} = 6.47 \text{ CM}$$

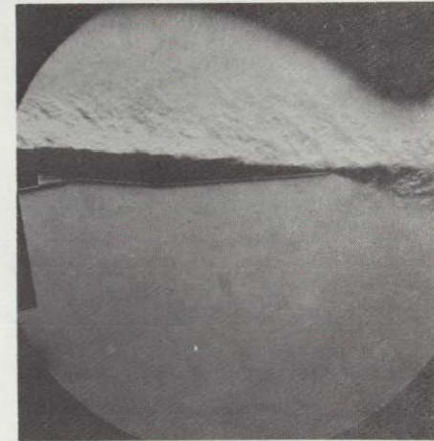
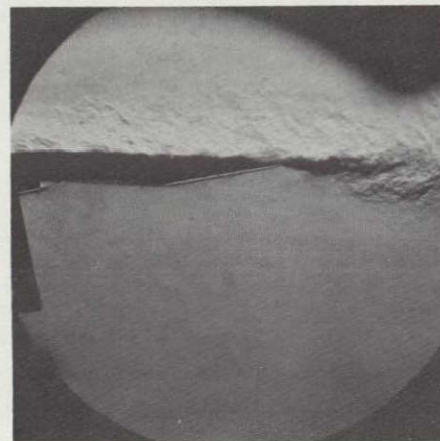
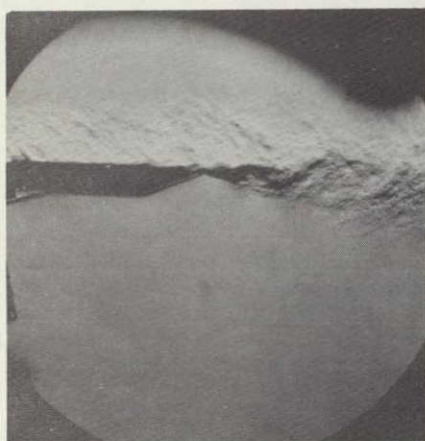
$$L_f = 21.77 \text{ CM}$$

$$L_{te} = 9.14 \text{ CM}$$

$$L_f = 24.44 \text{ CM}$$



(A) AR-8 NOZZLE, $R_c = 7.62 \text{ CM}$



(B) AR-4 NOZZLE, $R_c = \infty$

FIGURE 3-12. EFFECT OF TRAILING EDGE LENGTH BY SPANWISE SCHLIEREN PHOTOGRAPHY; $X_N = 0.20C$, $\theta_N = 20^\circ$, $\delta_f = 60^\circ$, $NPR = 1.47$

$$X_N = 0.20 \text{ C}$$

$$L_f = 24.44 \text{ CM}$$

$$X_N = 0.35 \text{ C}$$

$$L_f = 22.15 \text{ CM}$$

$$X_N = 0.50 \text{ C}$$

$$L_f = 19.86 \text{ CM}$$

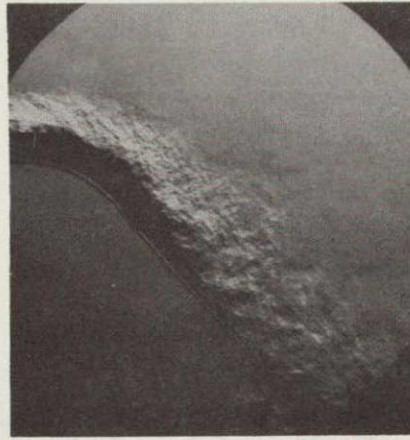
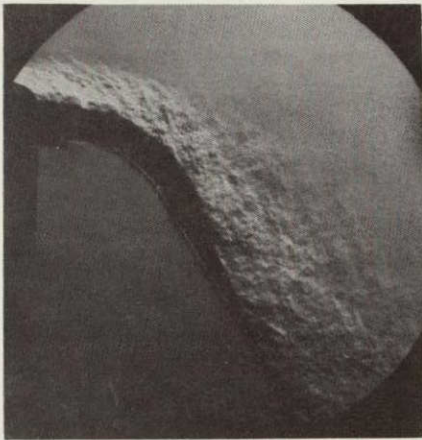


FIGURE 3-13. EFFECT OF NOZZLE CHORDWISE LOCATION BY SPANWISE SCHLIEREN PHOTOGRAPHY; AR-8 NOZZLE, $\theta_N = 20^\circ$, $R_c = 7.62 \text{ CM}$, $\delta_f = 60^\circ$, $L_{te} = 9.14 \text{ CM}$. $\text{NPR} = 1.47$

SHOCKS

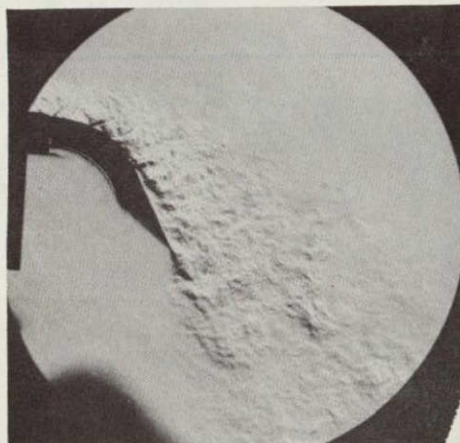


FIGURE 3-14. SPANWISE SCHLIEREN VIEW OF SHOCKS; AR-4 NOZZLE, $X_N = 0.20 \text{ C}$, $\theta_N = 20^\circ$, $R_c = 5.08 \text{ CM}$, $\delta_f = 60^\circ$, $L_{te} = 3.81 \text{ CM}$, $\text{NPR} = 2.19$.

PARALLEL TO T.E.

NORMAL TO T.E.

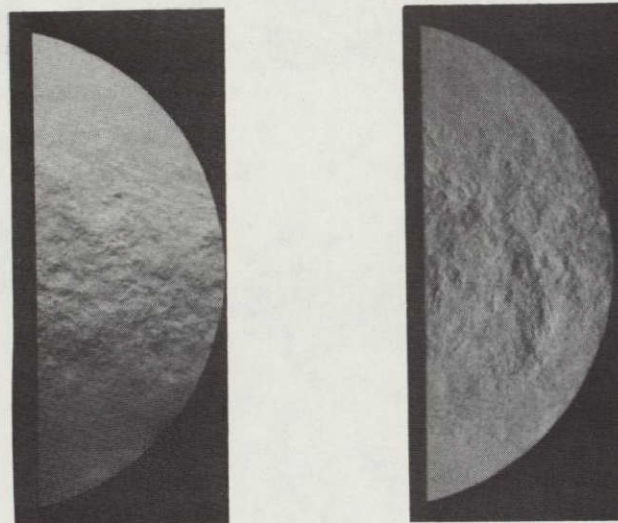


FIGURE 3-15. EFFECT OF KNIFE-EDGE ORIENTATION
ON TRANSVERSE SCHLIEREN VIEW;
AR-8 NOZZLE, $x_N=0.20C$, $\theta_N=20^\circ$,
 $R_c=7.62\text{CM}$, $\delta_f=60^\circ$, $L_{te}=8.45\text{CM}$,
 $\text{NPR}=1.47$.

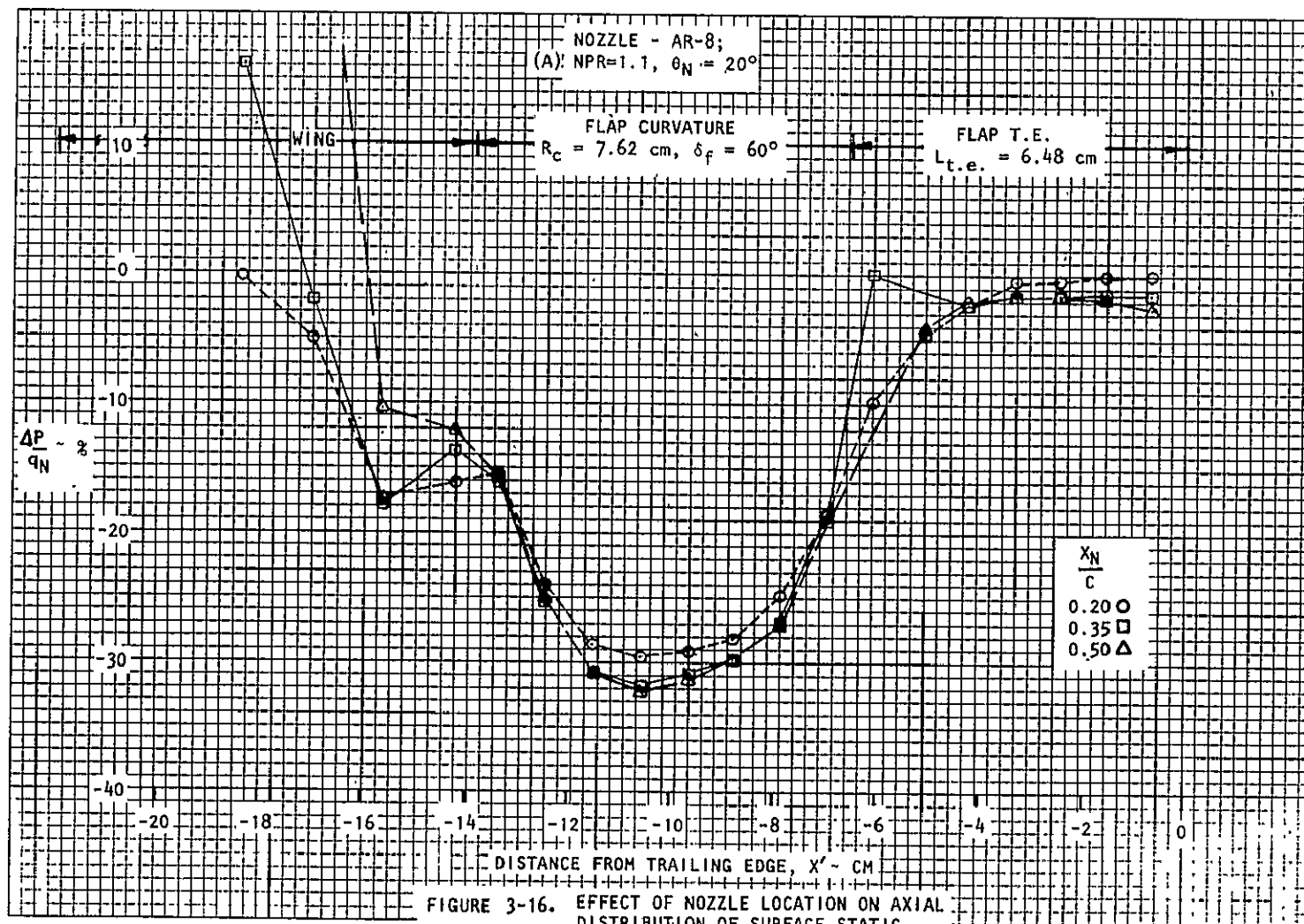
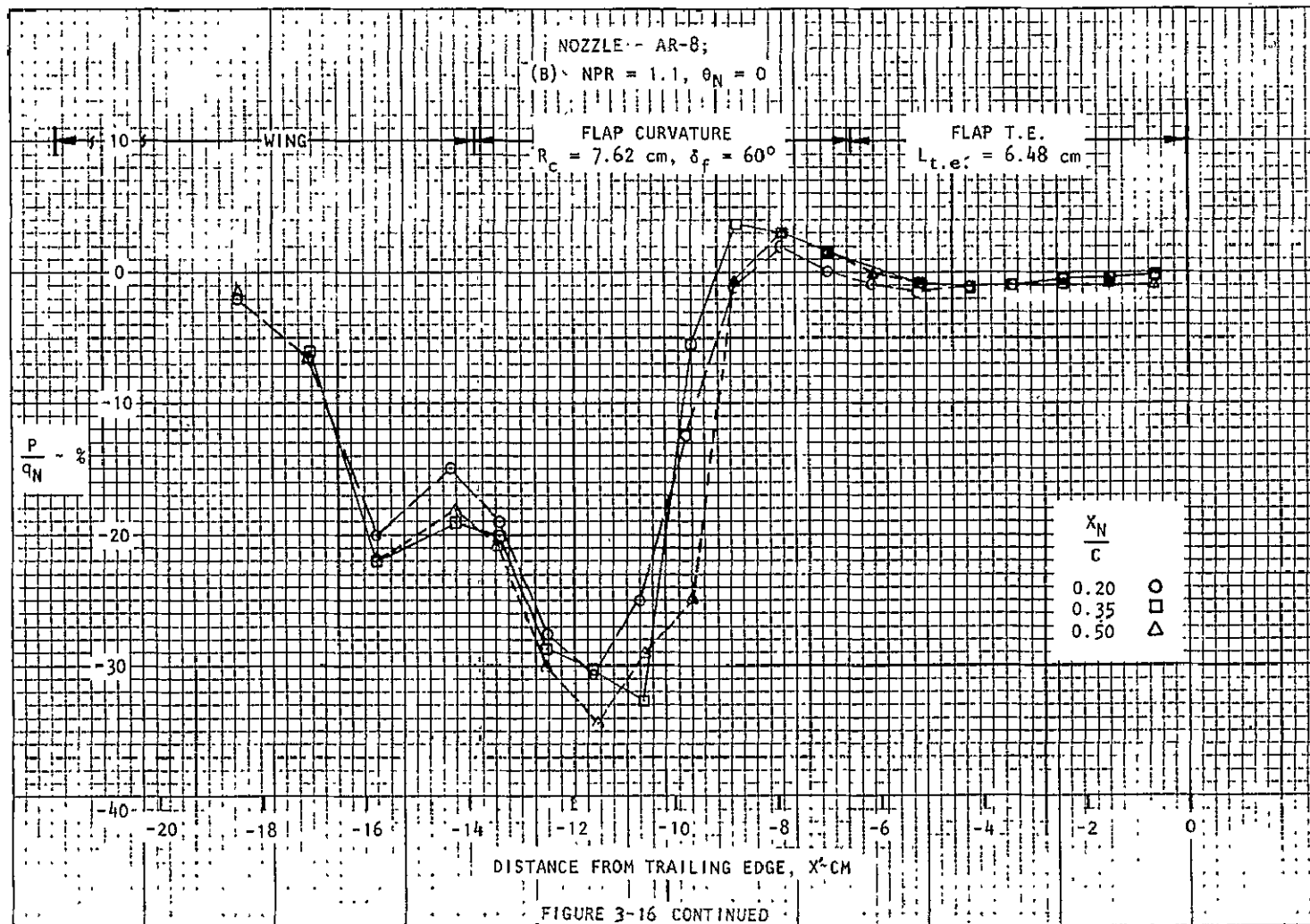


FIGURE 3-16. EFFECT OF NOZZLE LOCATION ON AXIAL DISTRIBUTION OF SURFACE STATIC PRESSURE, $Y = 0$



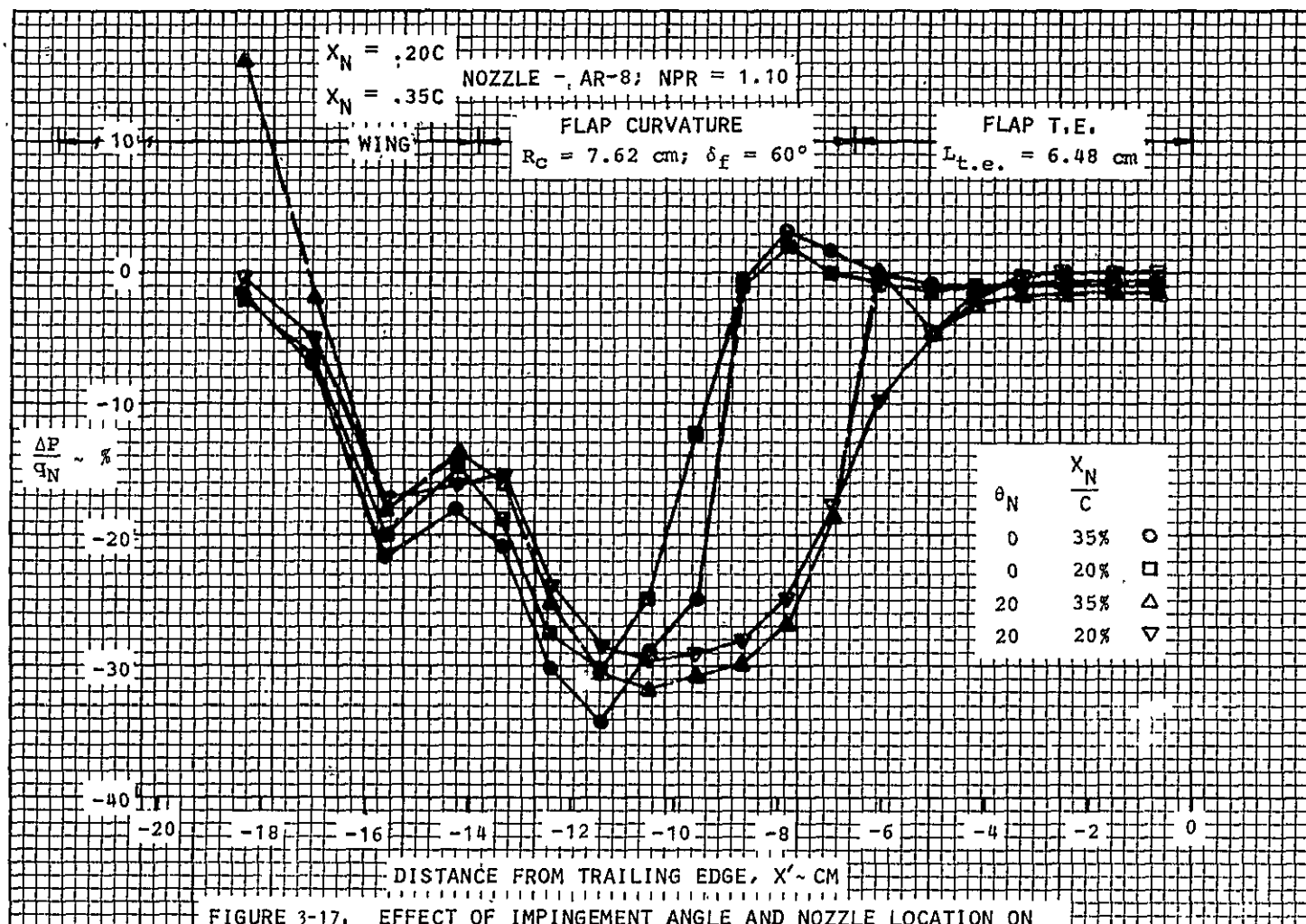
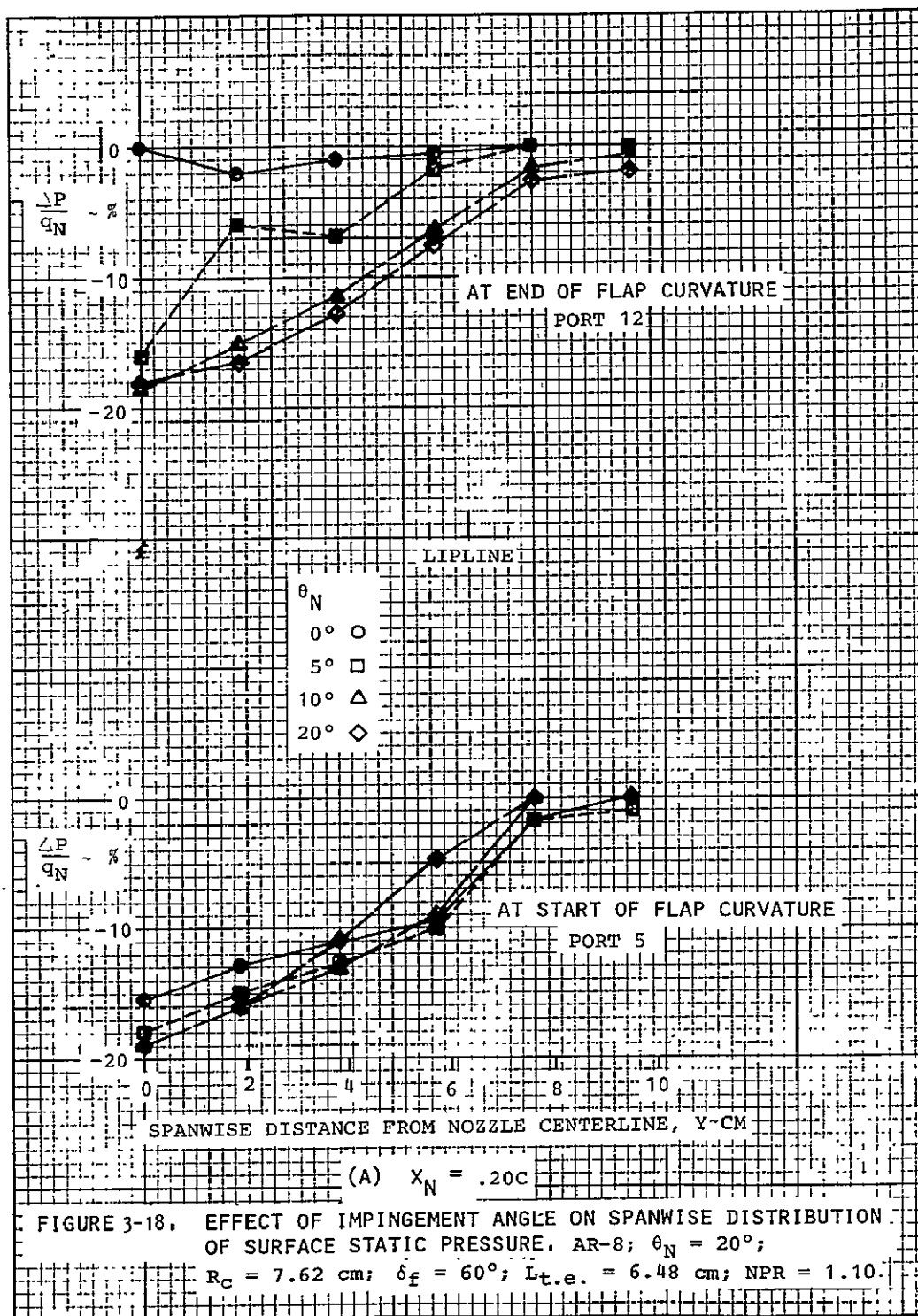


FIGURE 3-17. EFFECT OF IMPINGEMENT ANGLE AND NOZZLE LOCATION ON AXIAL DISTRIBUTION OF SURFACE STATIC PRESSURE, $Y=0$.



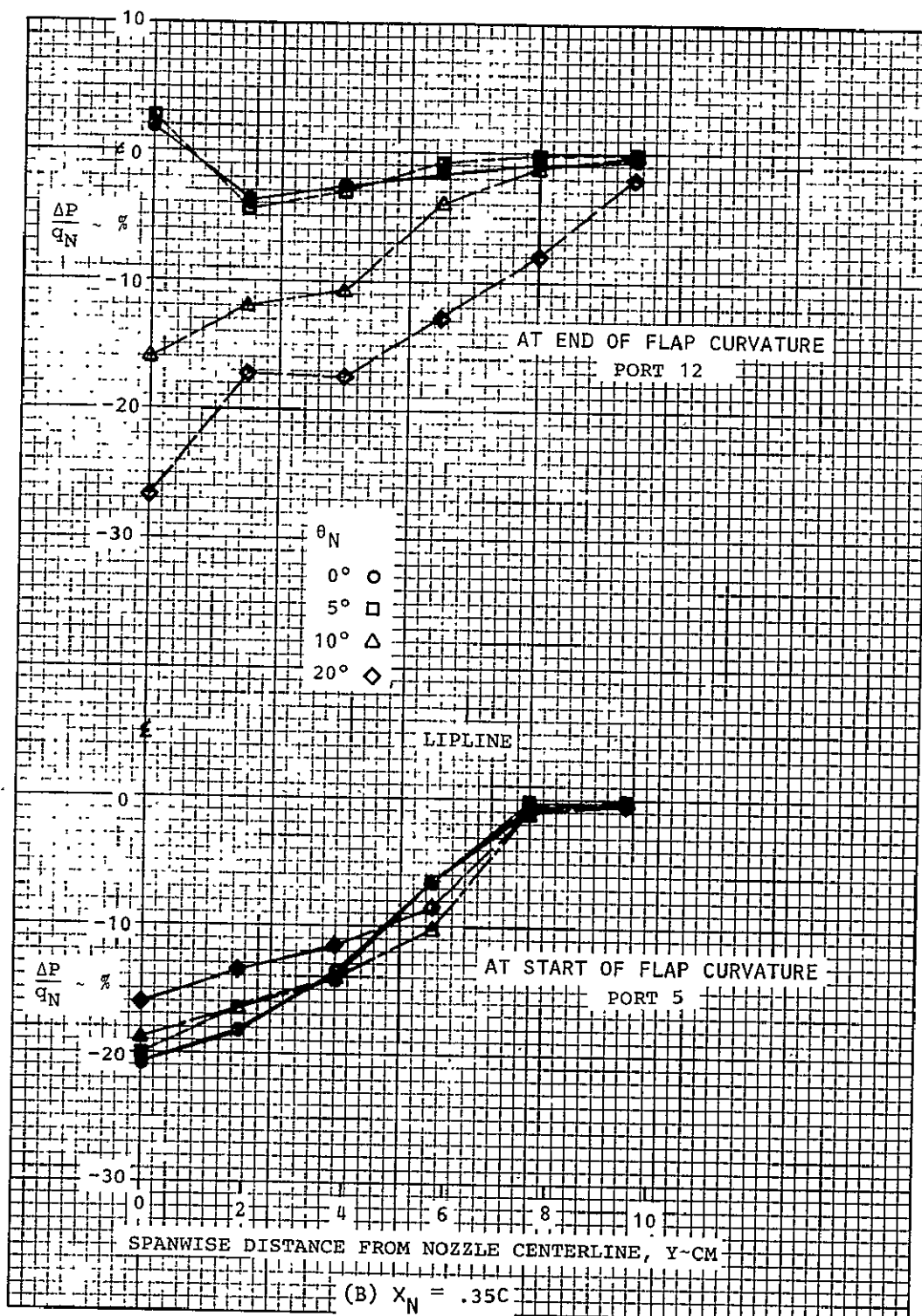


FIGURE 3-18. CONTINUED.

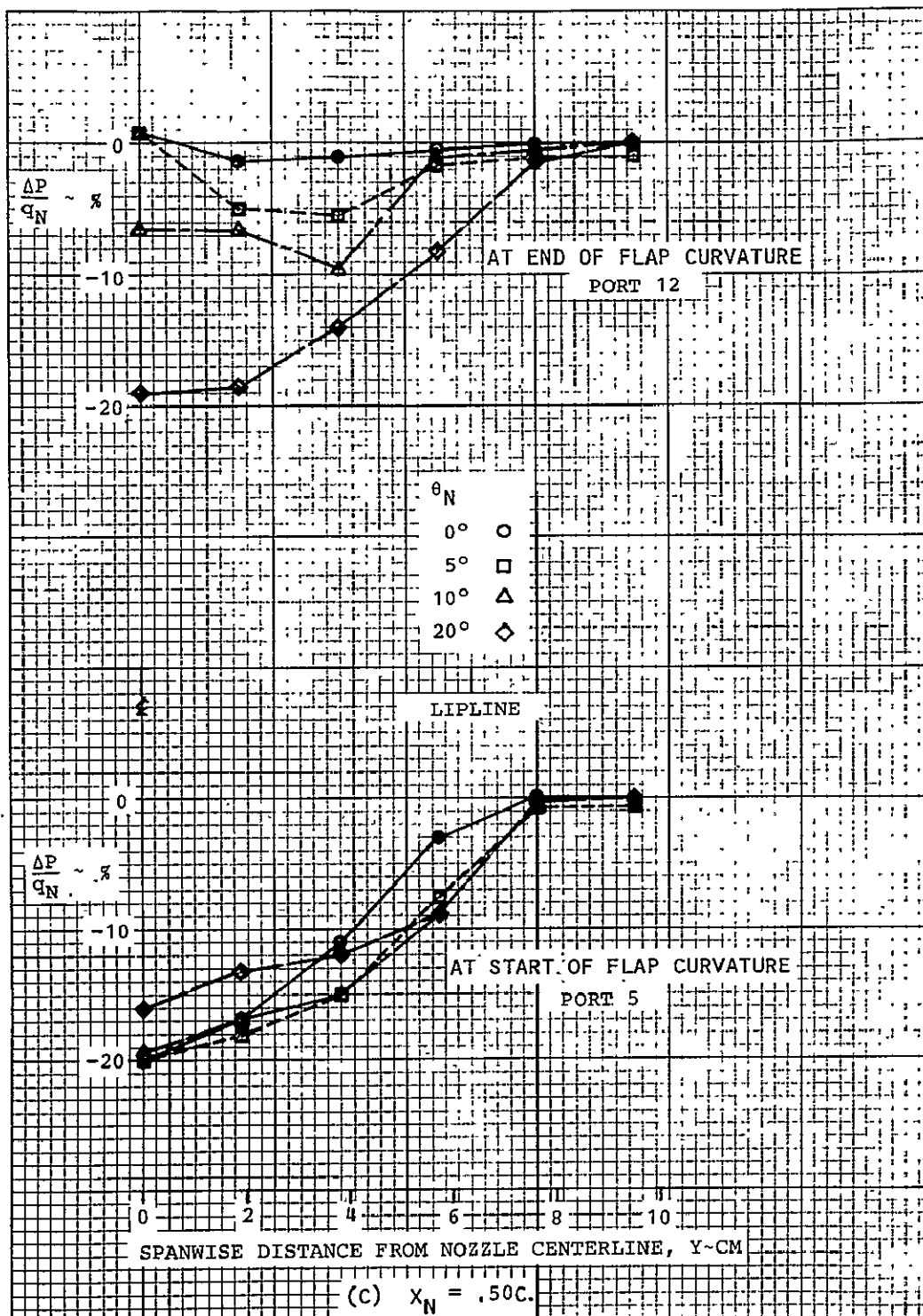


FIGURE 3-18. CONCLUDED.

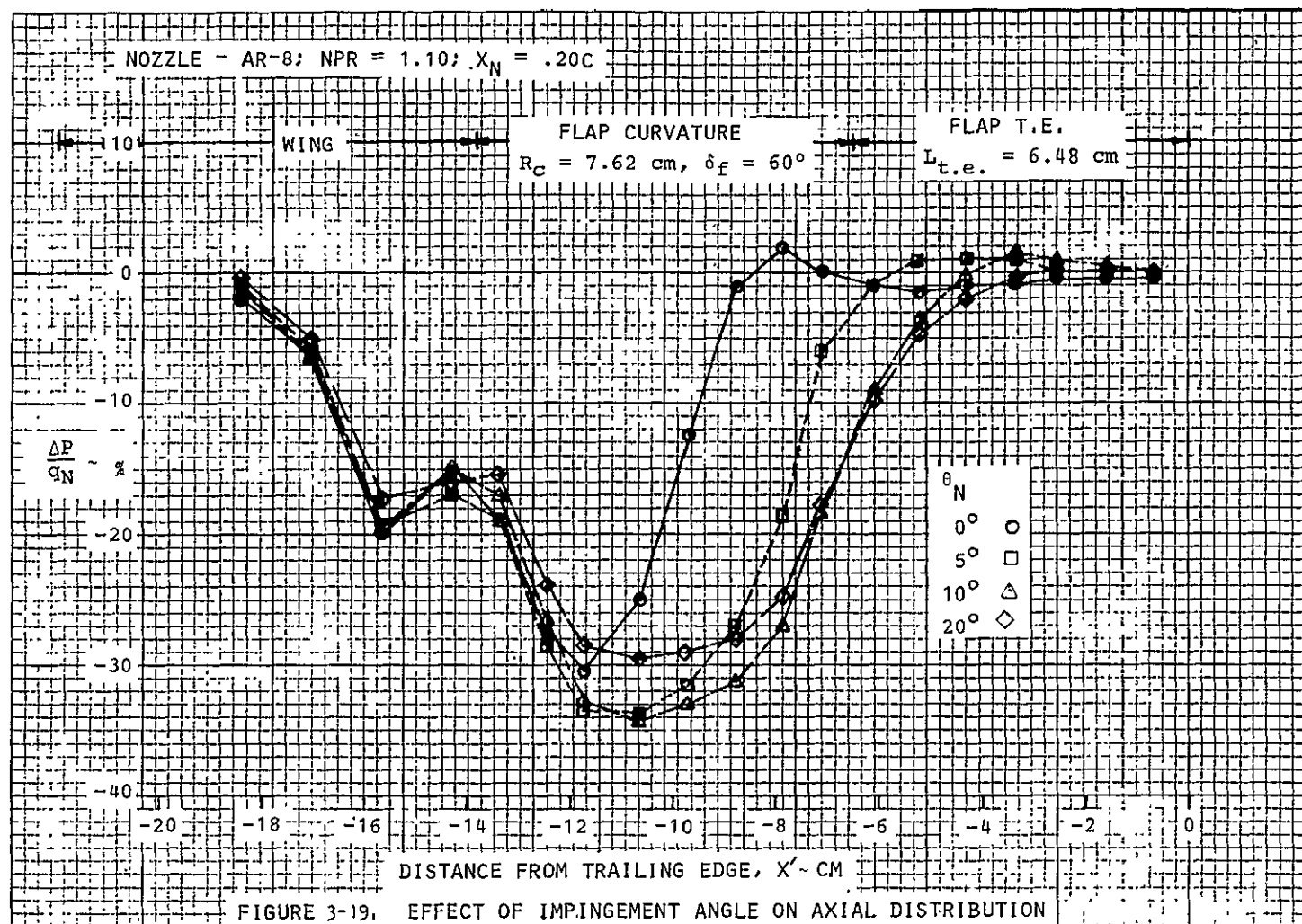
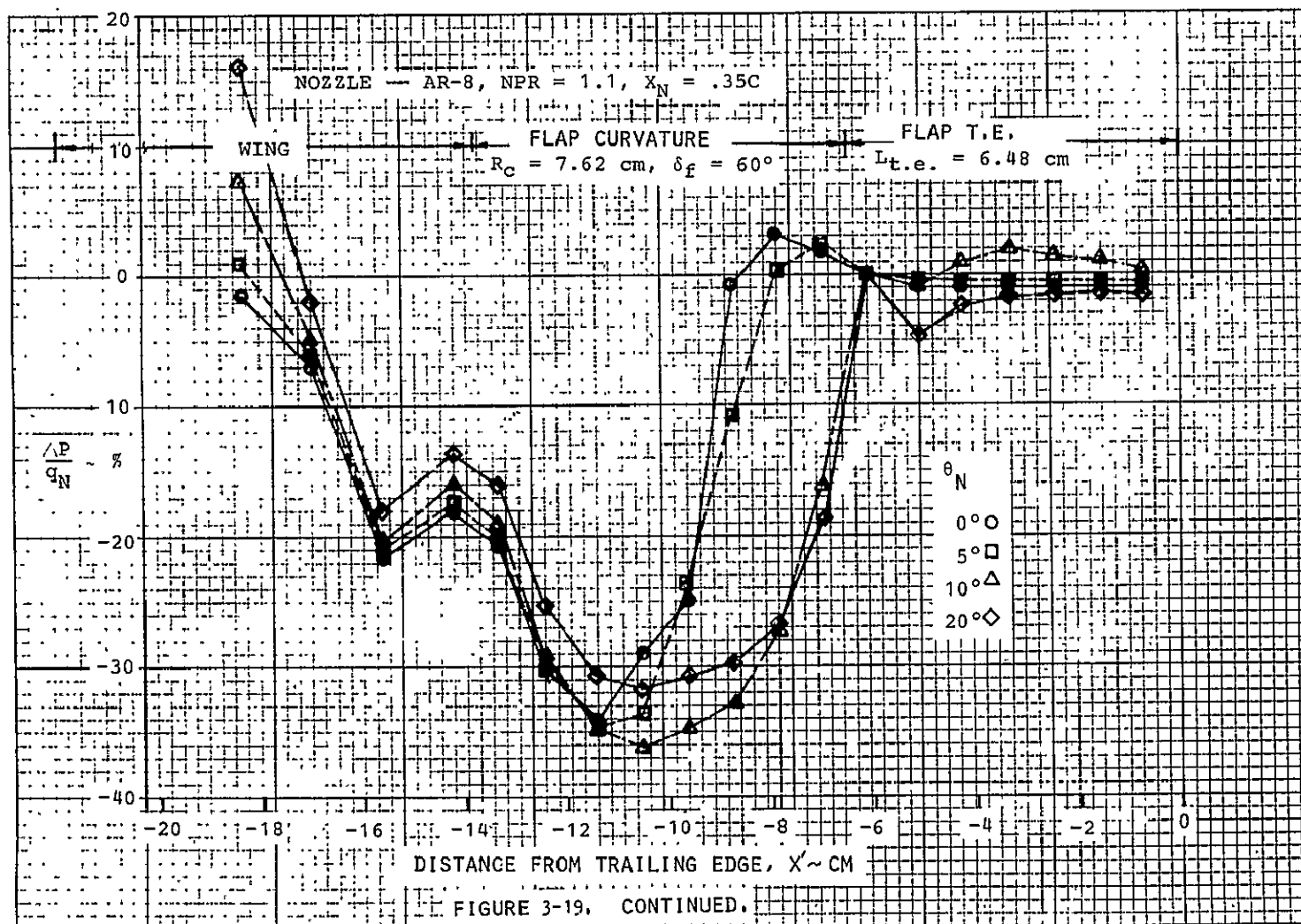


FIGURE 3-19. EFFECT OF IMPINGEMENT ANGLE ON AXIAL DISTRIBUTION OF SURFACE STATIC PRESSURE, $Y = 0$.

(A) NPR = 1.10; $X_N = .20C$

(B) NPR = 1.10; $x_N = .35C$

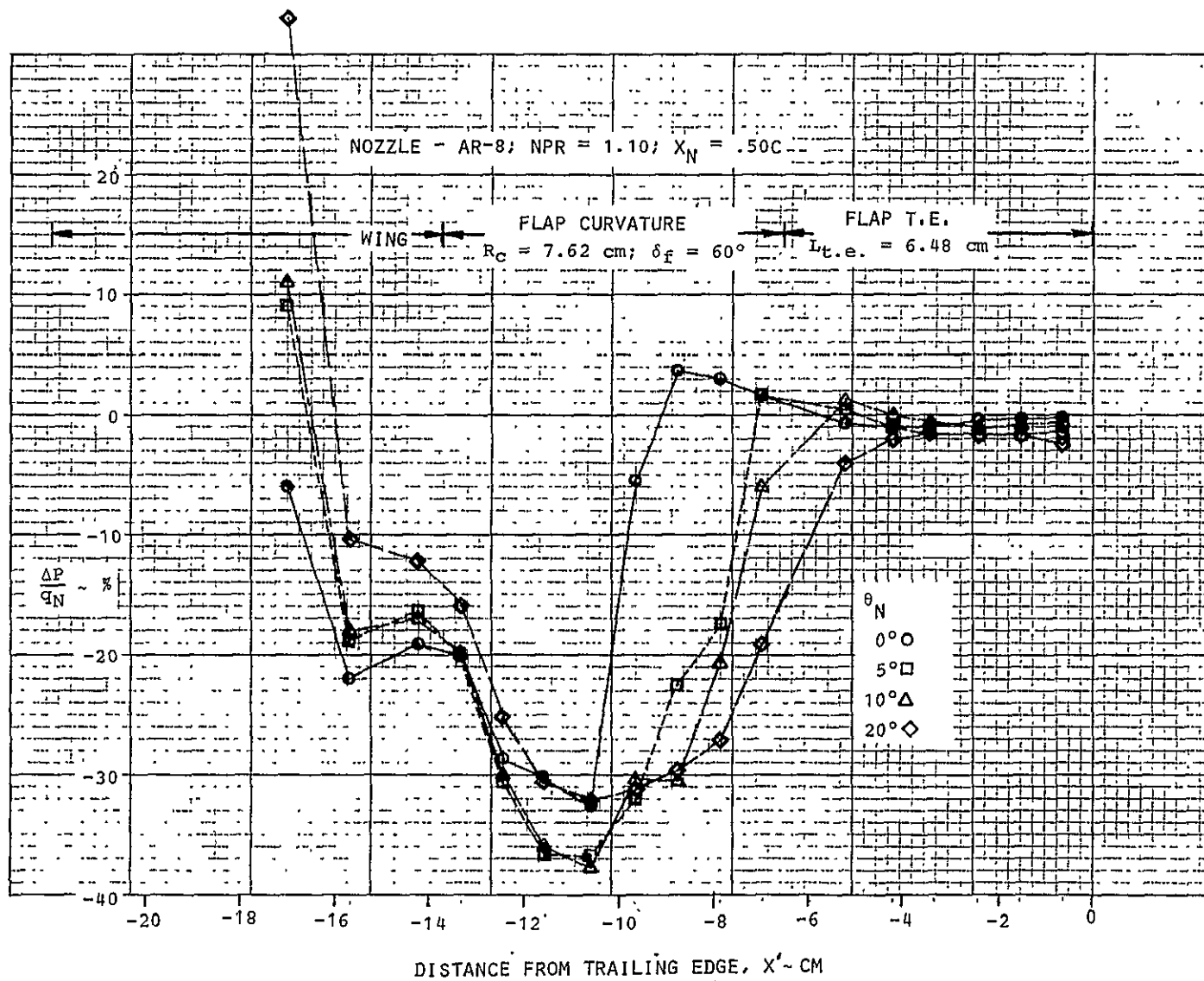


FIGURE 3-19, CONTINUED.

(C) NPR = 1.10; $X_N = .50C$

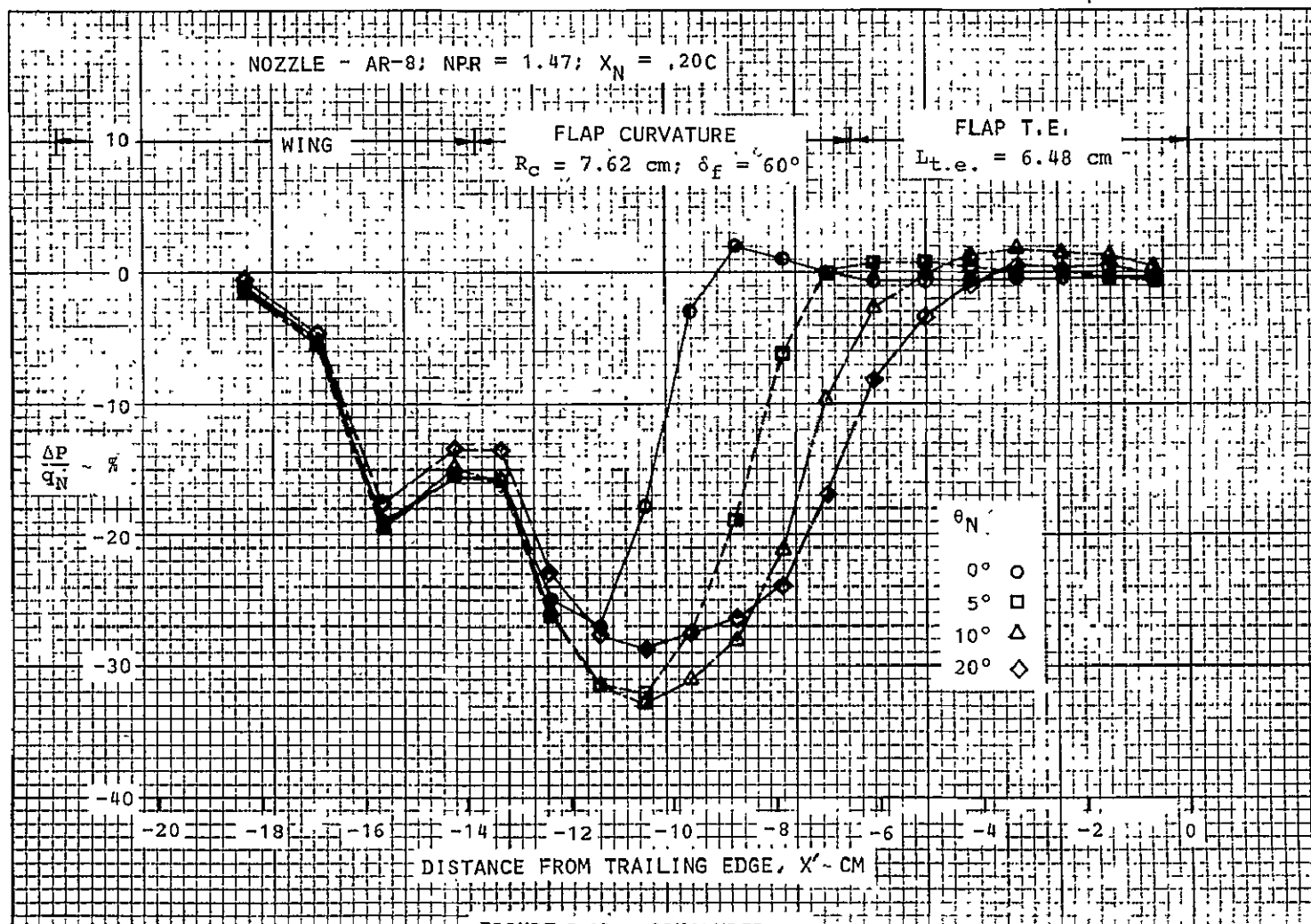
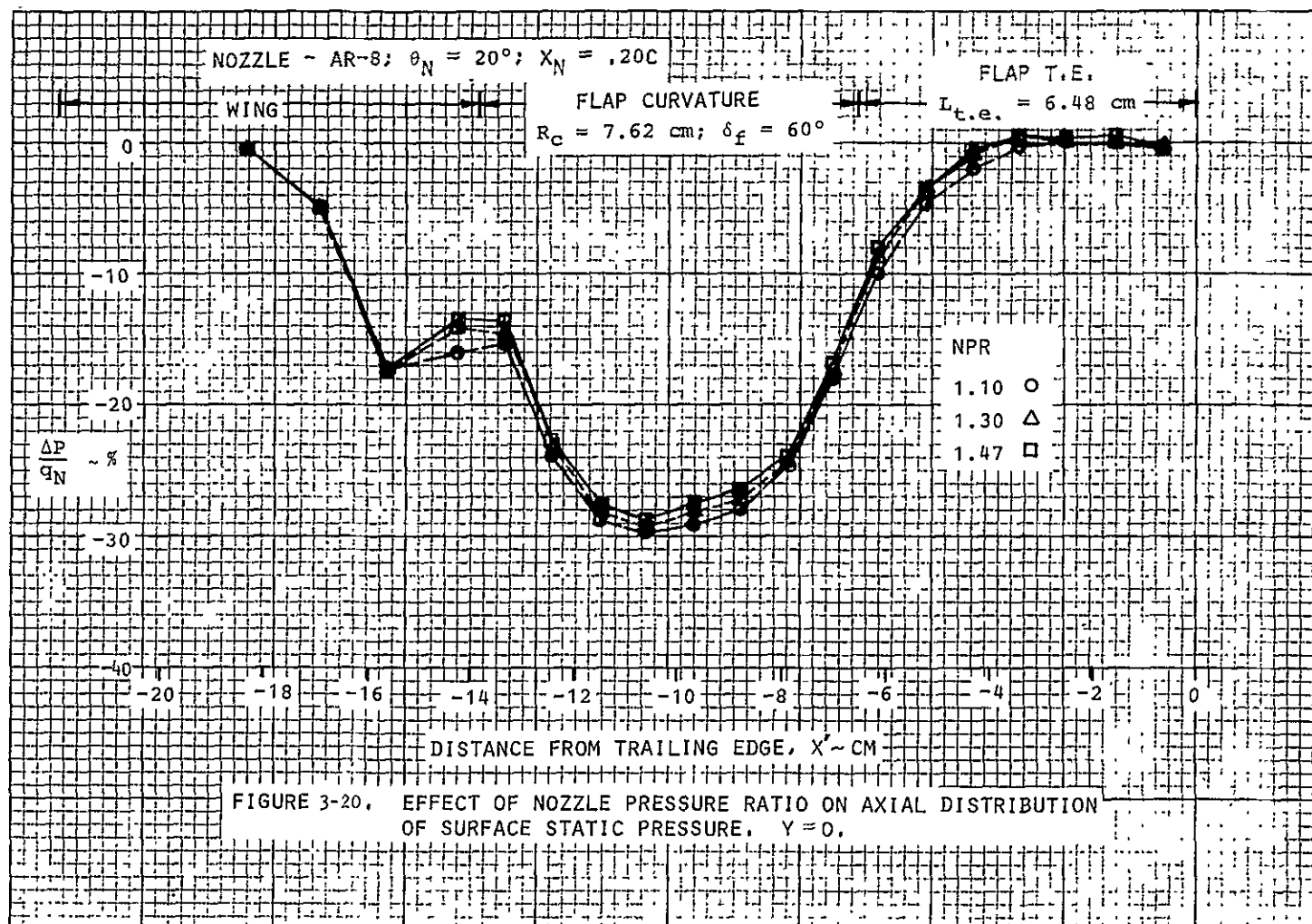


FIGURE 3-19, CONCLUDED.

(D) NPR = 1.47; $X_N = .20C$



89-3

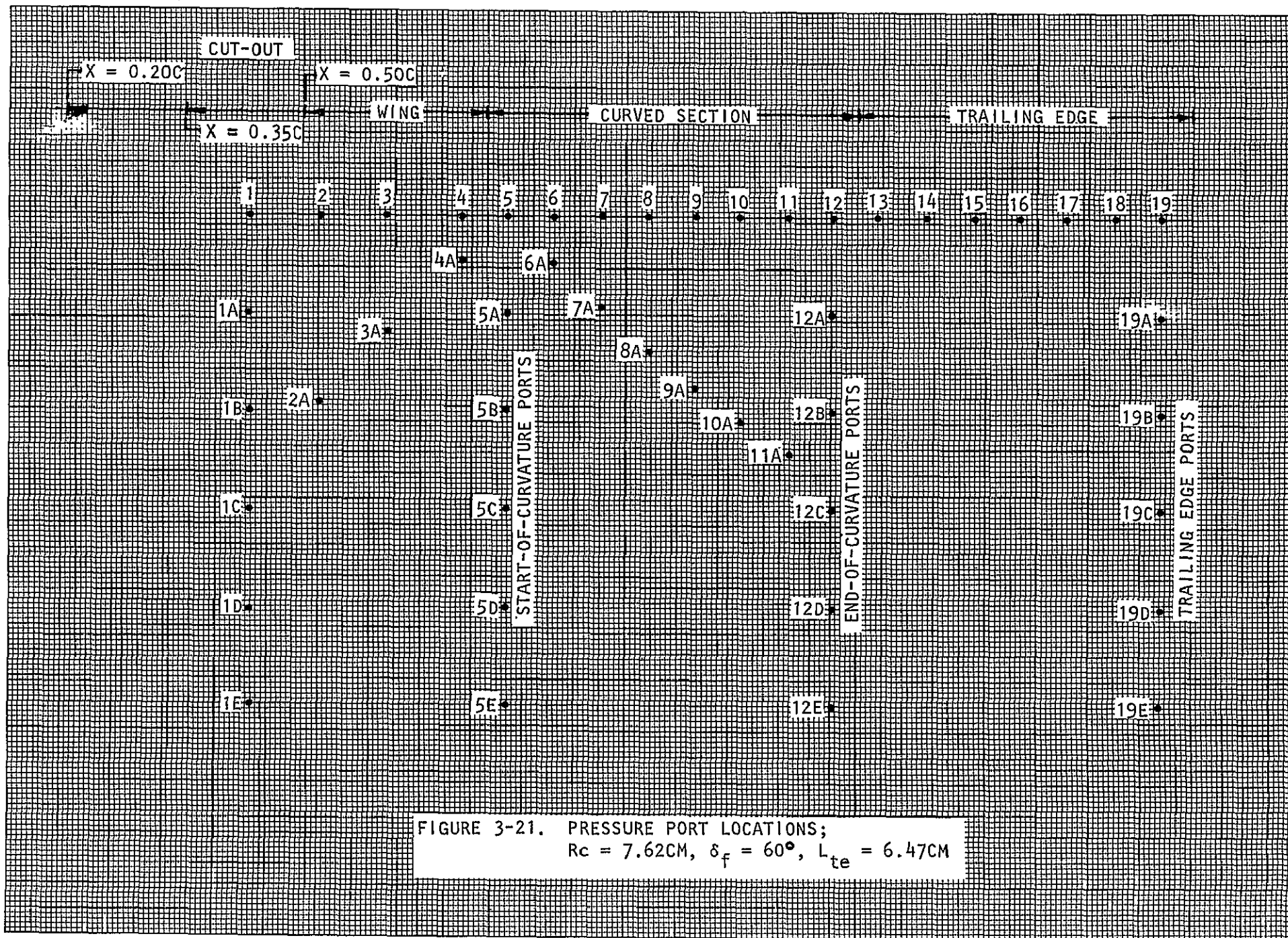
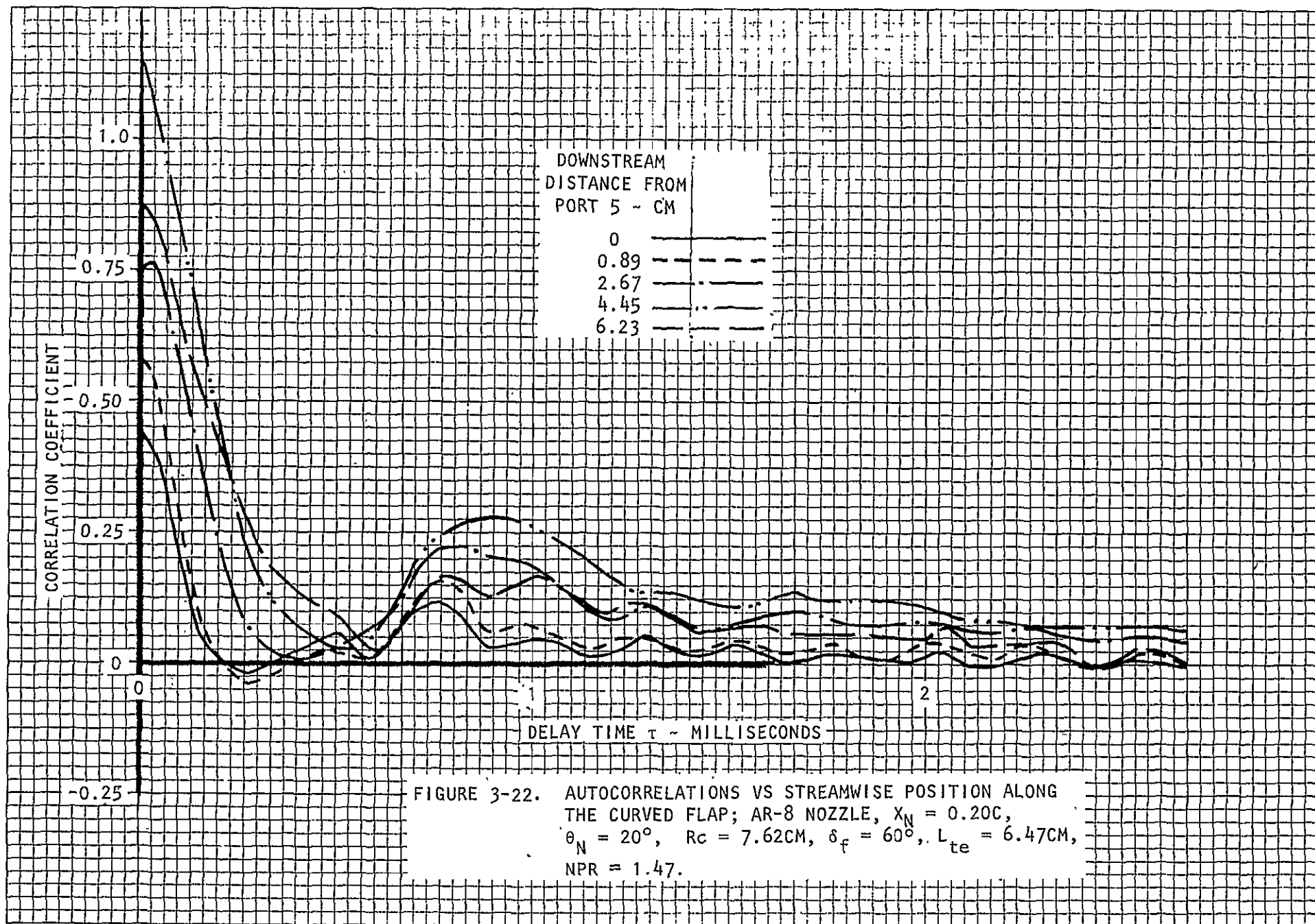
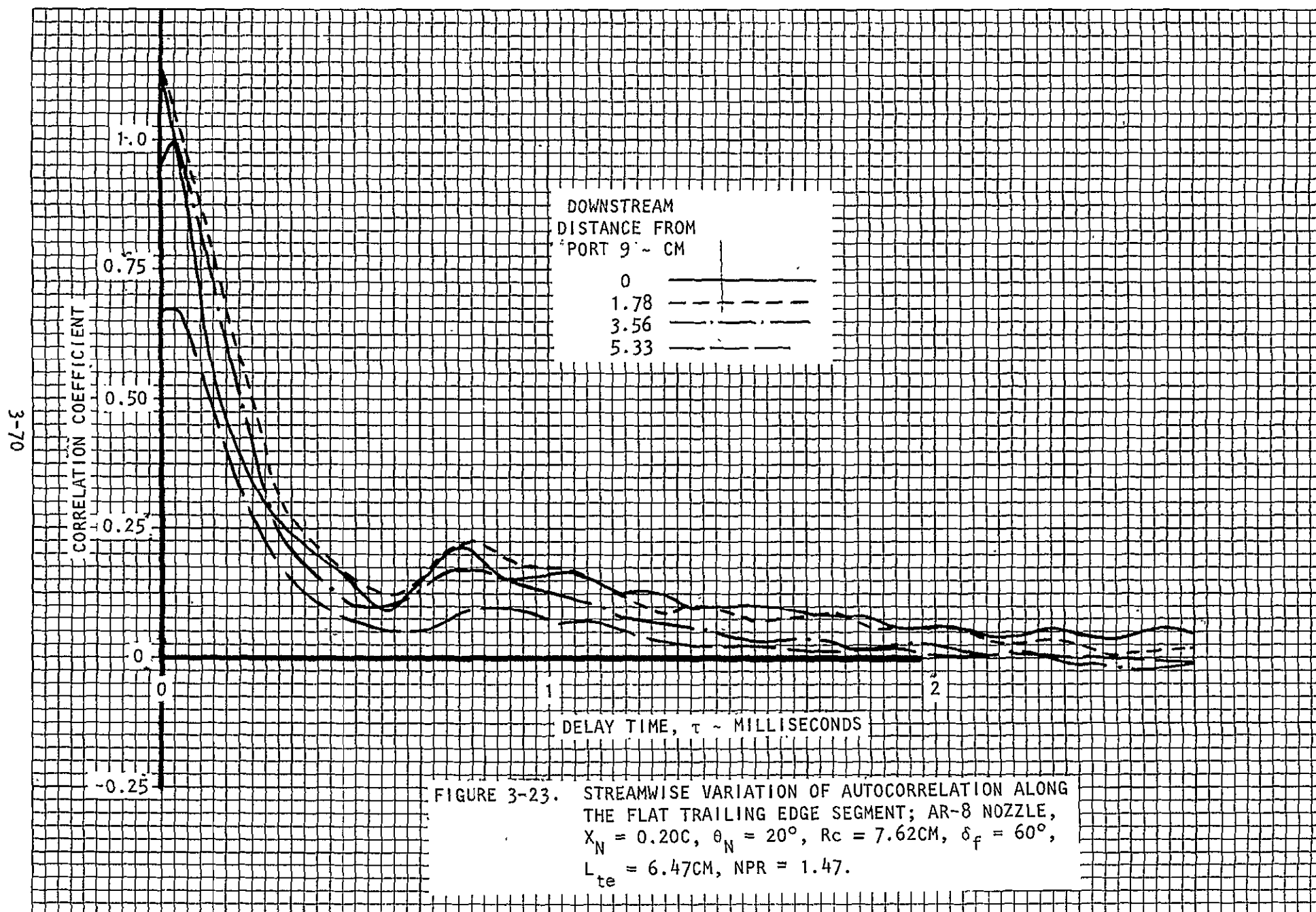


FIGURE 3-21. PRESSURE PORT LOCATIONS;
 $R_c = 7.62\text{CM}$, $\delta_f = 60^\circ$, $L_{te} = 6.47\text{CM}$

3-69







AUTOCORRELATION ~ ARBITRARY UNITS

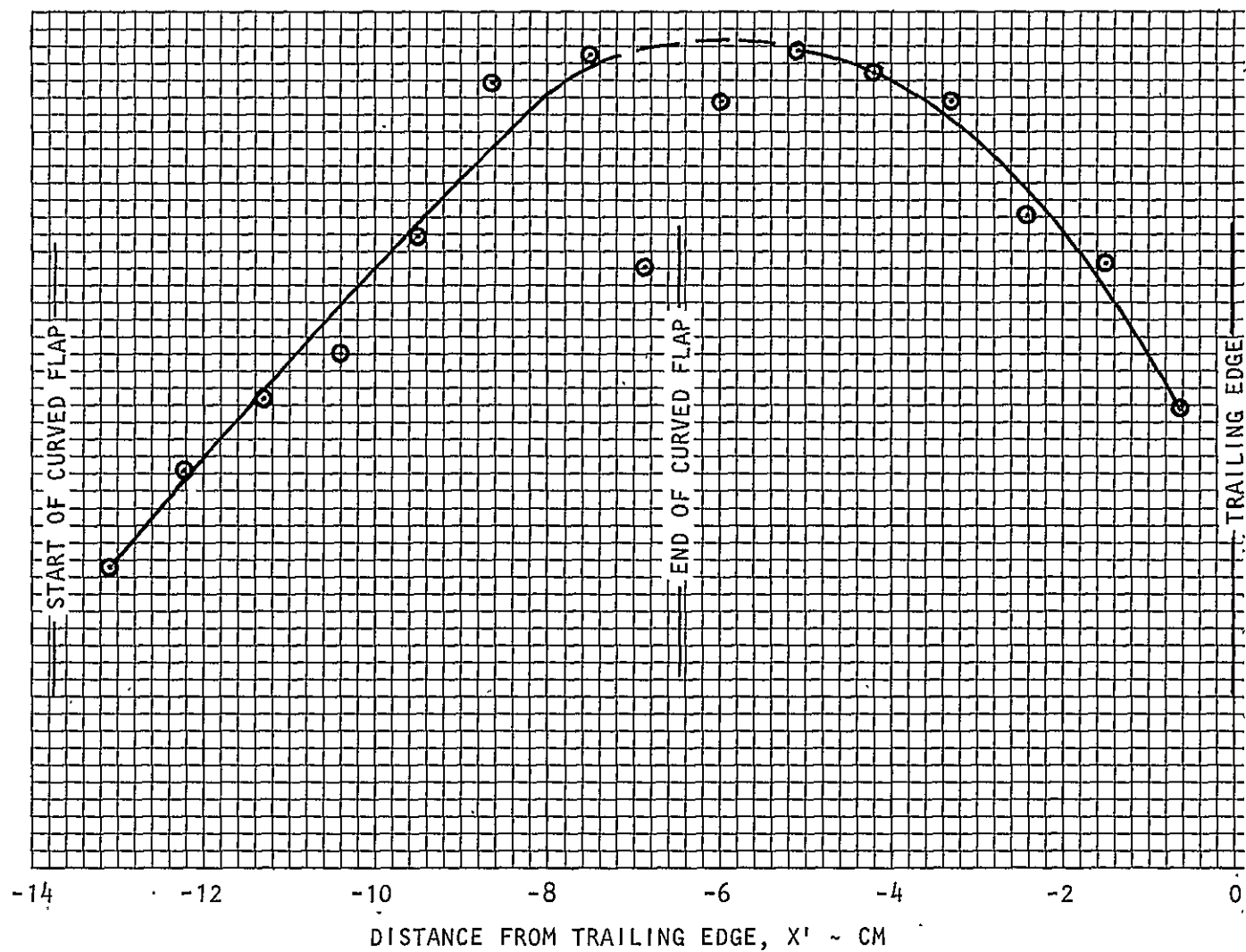
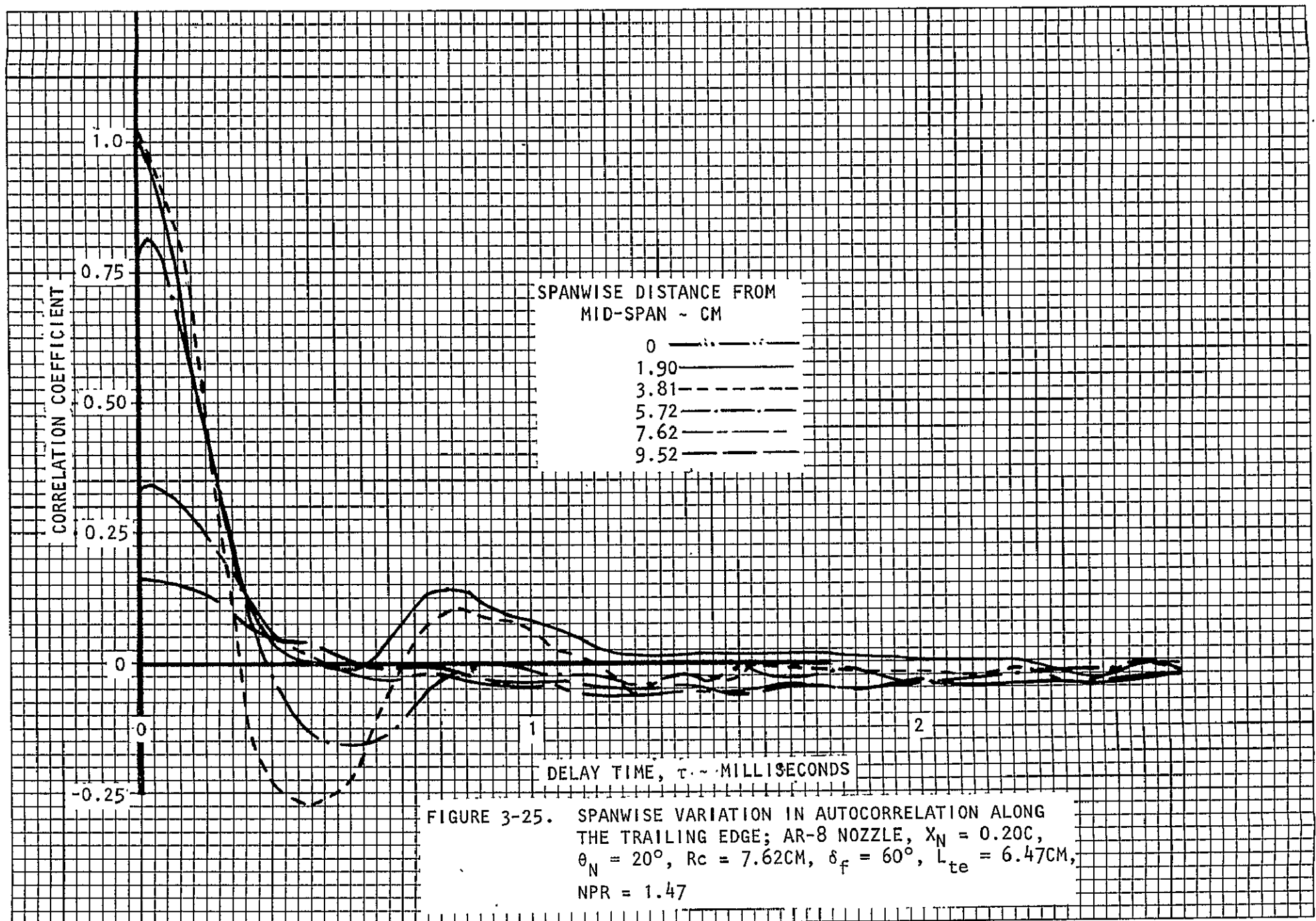


FIGURE 3-24. STREAMWISE DISTRIBUTION OF AUTOCORRELATION; AR-8 NOZZLE:
 $X_N = 0.2$ c; $\theta_N = 20^\circ$; NPR = 1.1; $R_C = 7.62$ cm; $\delta_f = 60^\circ$;
 $L_{te} = 6.47$ cm.

3-72



3-73

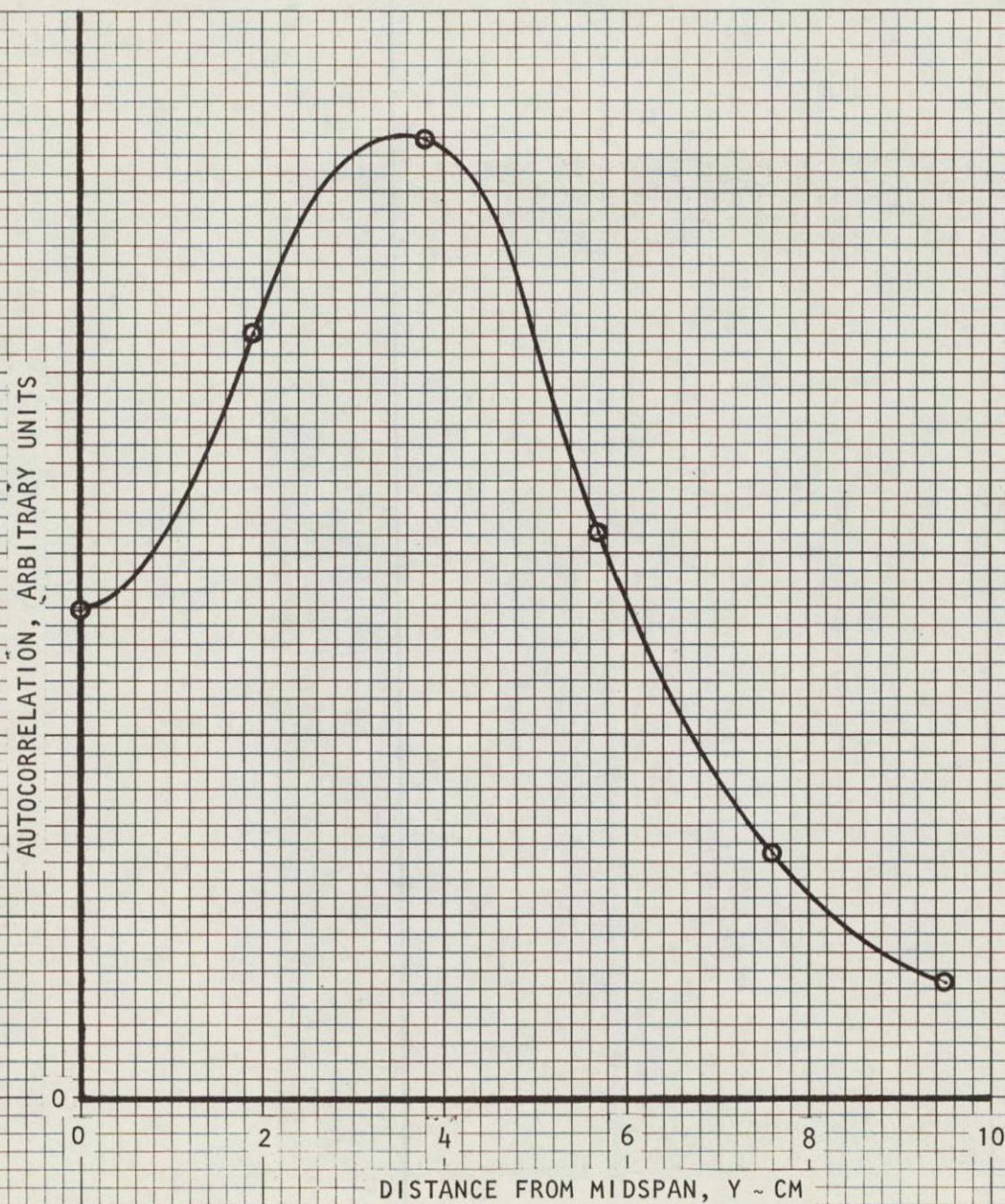


FIGURE 3-26. SPANWISE DISTRIBUTION OF AUTOCORRELATION.

AR-8 NOZZLE; $x_N = 0.2$ c; $\theta_N = 20^\circ$; NPR = 1.1; $R_C = 7.62$ cm;
 $\delta_f = 60^\circ$; $L_{te} = 6.47$ cm.

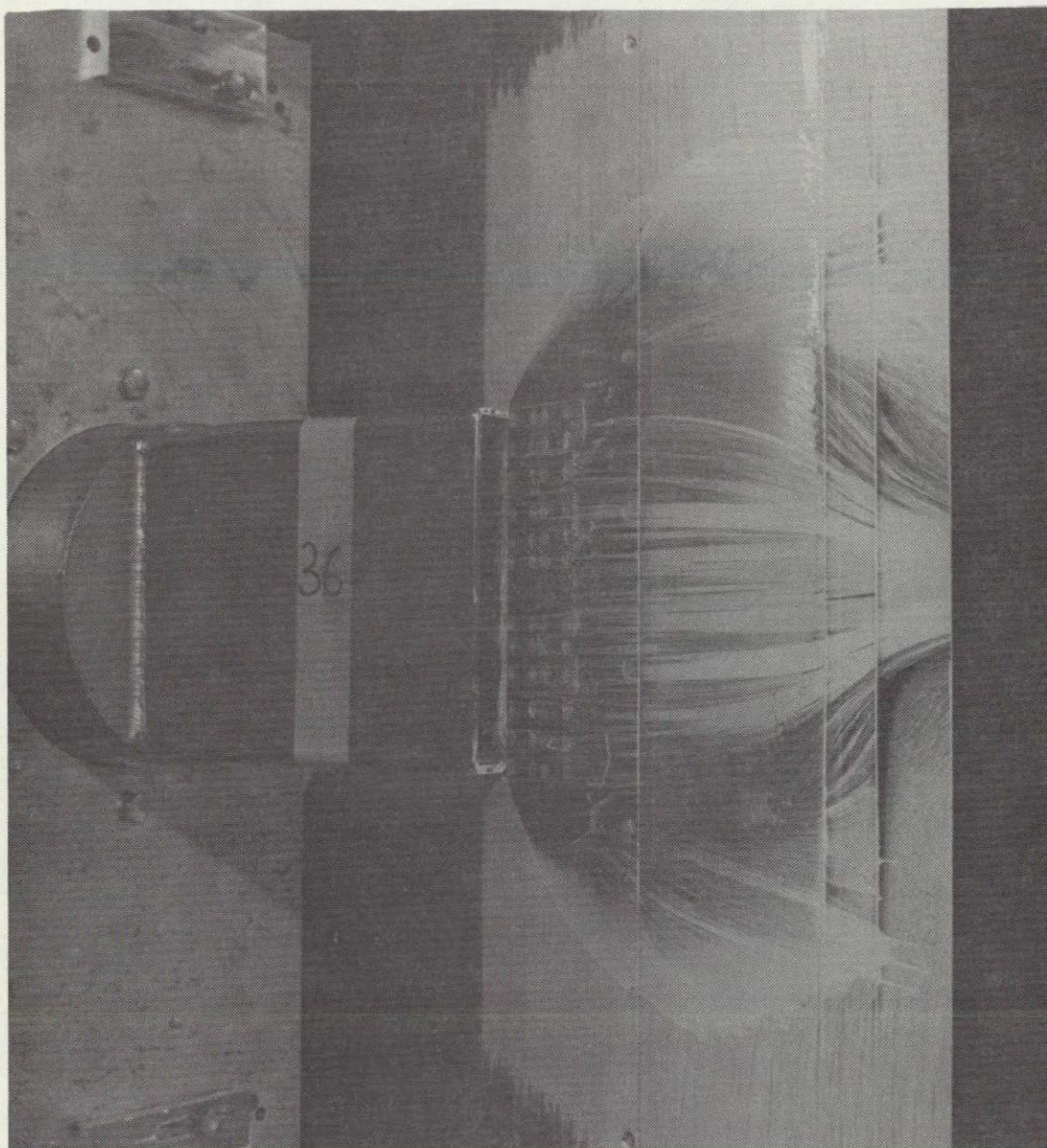


FIGURE 3-27. SURFACE OIL FLOW SHOWING EDGE ROLL-UP; AR-8 NOZZLE,
 $x_N = 0.2$ c, $\theta_N = 20^\circ$, NPR = 1.55, $R_C = 7.62$ cm,
 $\delta_f = 60^\circ$, $L_{te} = 3.81$ cm

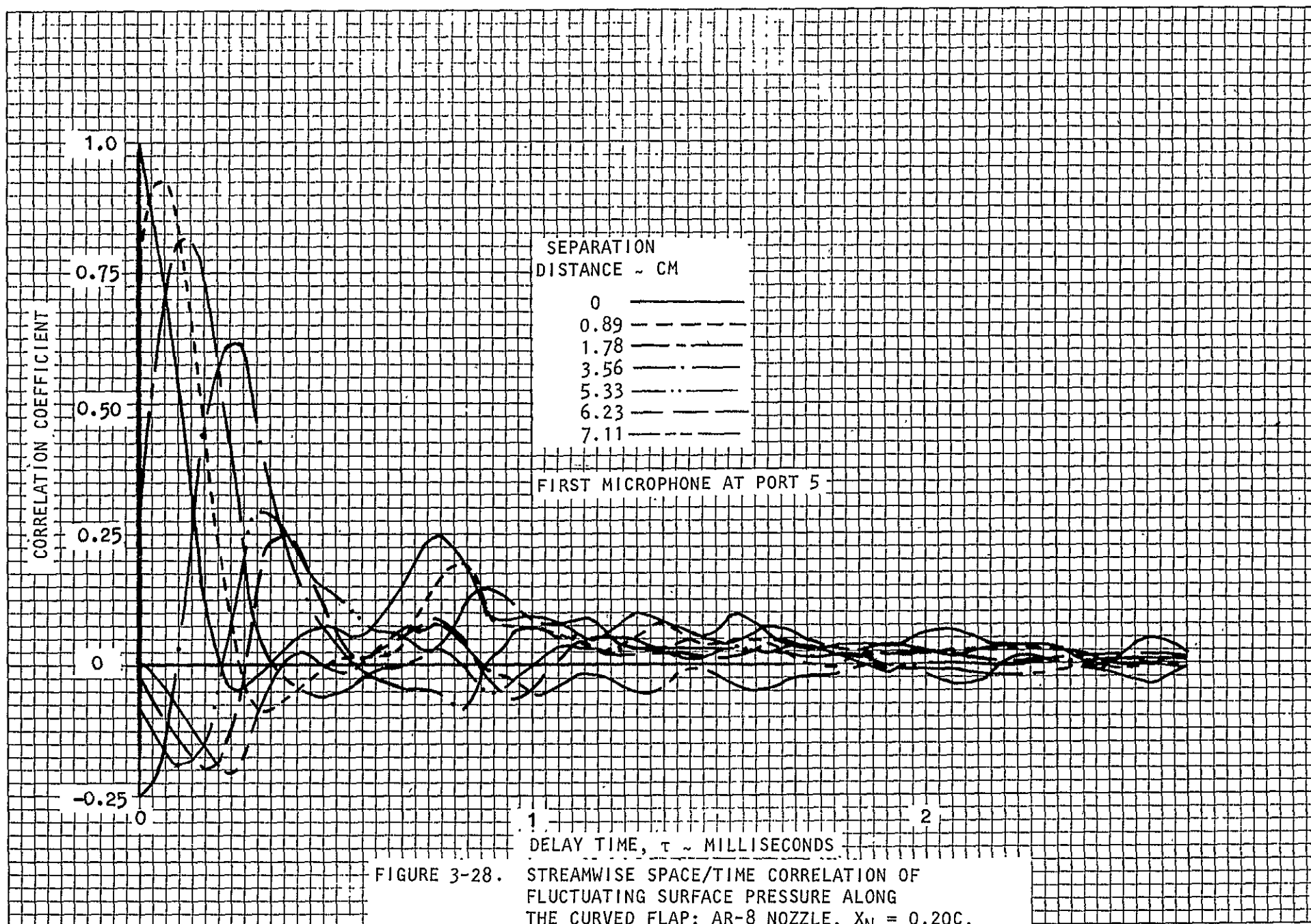
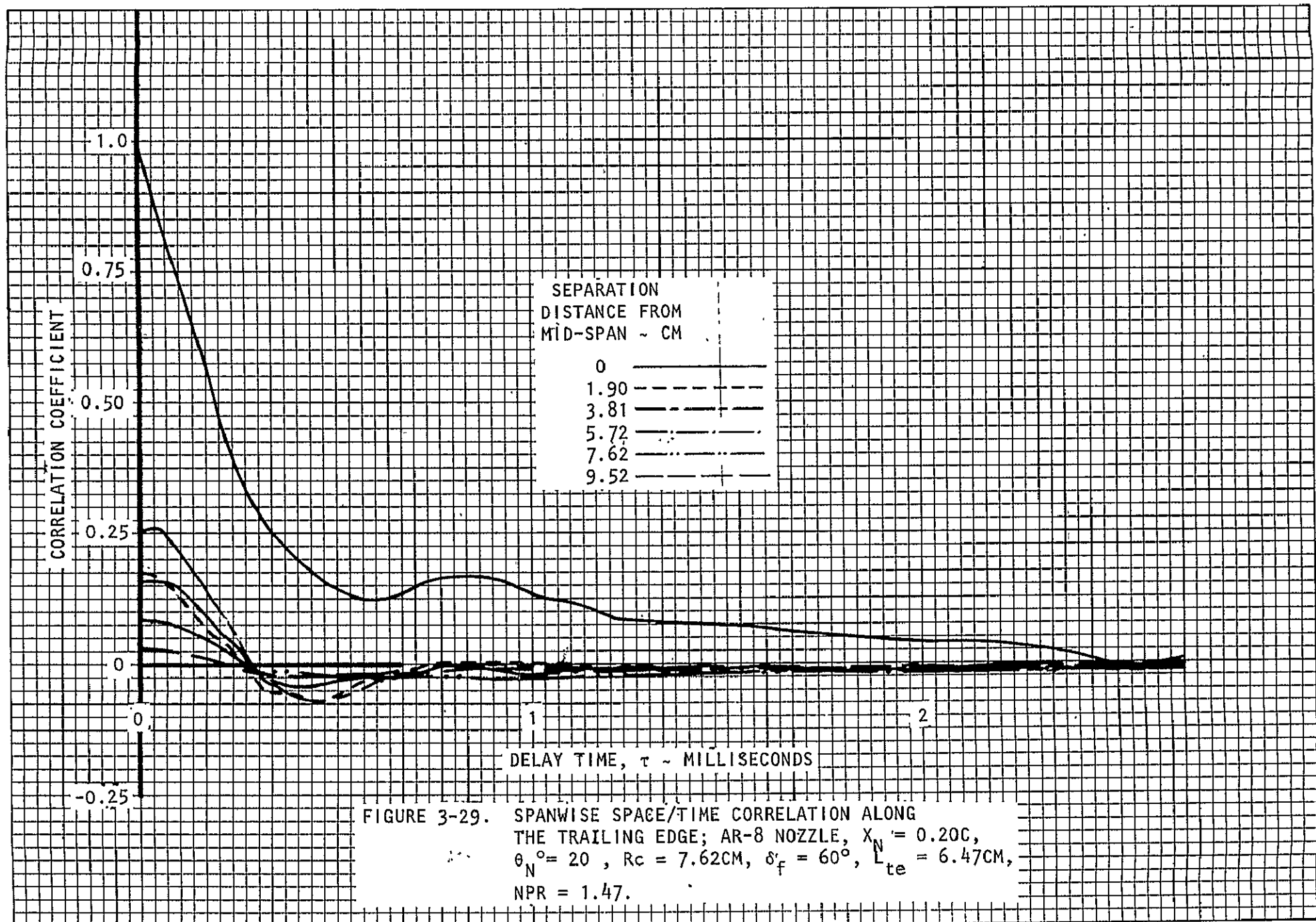


FIGURE 3-28. STREAMWISE SPACE/TIME CORRELATION OF FLUCTUATING SURFACE PRESSURE ALONG THE CURVED FLAP; AR-8 NOZZLE, $x_N = 0.20C$, $\theta_N = 20^\circ$, $R_c = 7.62\text{CM}$, $\delta_f = 60^\circ$, $L_{te} = 6.47\text{CM}$, $\text{NPR} = 1.47$.

3-76



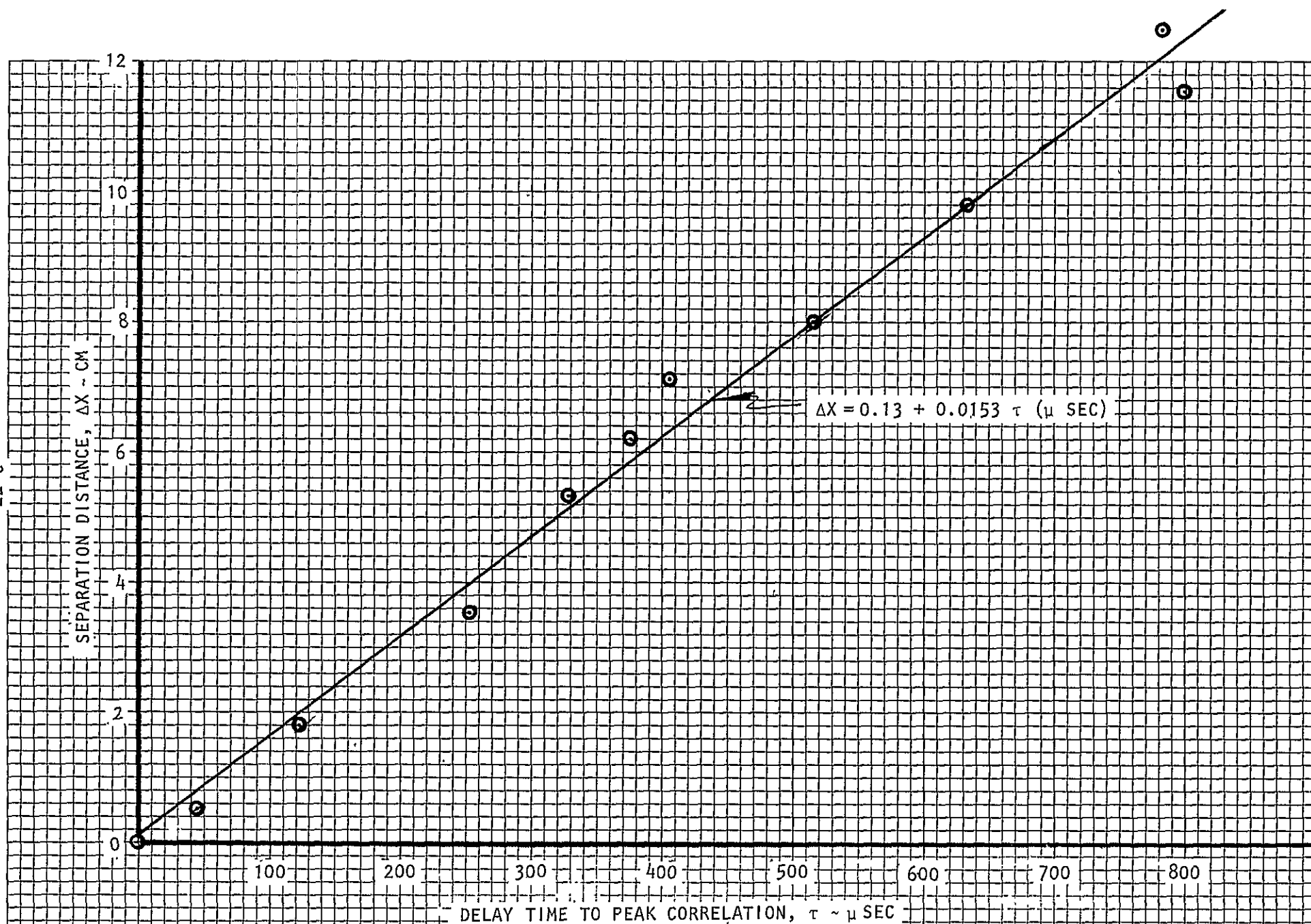


FIGURE 3-30. CURVE-FIT FOR CONVECTION VELOCITY COMPUTATION.
 AR-8 NOZZLE; $X_N = 0.2 \text{ c}$; $\theta_N = 20^\circ$; $\text{NPR} = 1.1$; $R_C = 7.62 \text{ cm}$;
 $\delta_f = 60^\circ$; $L_{te} = 6.47 \text{ cm}$.

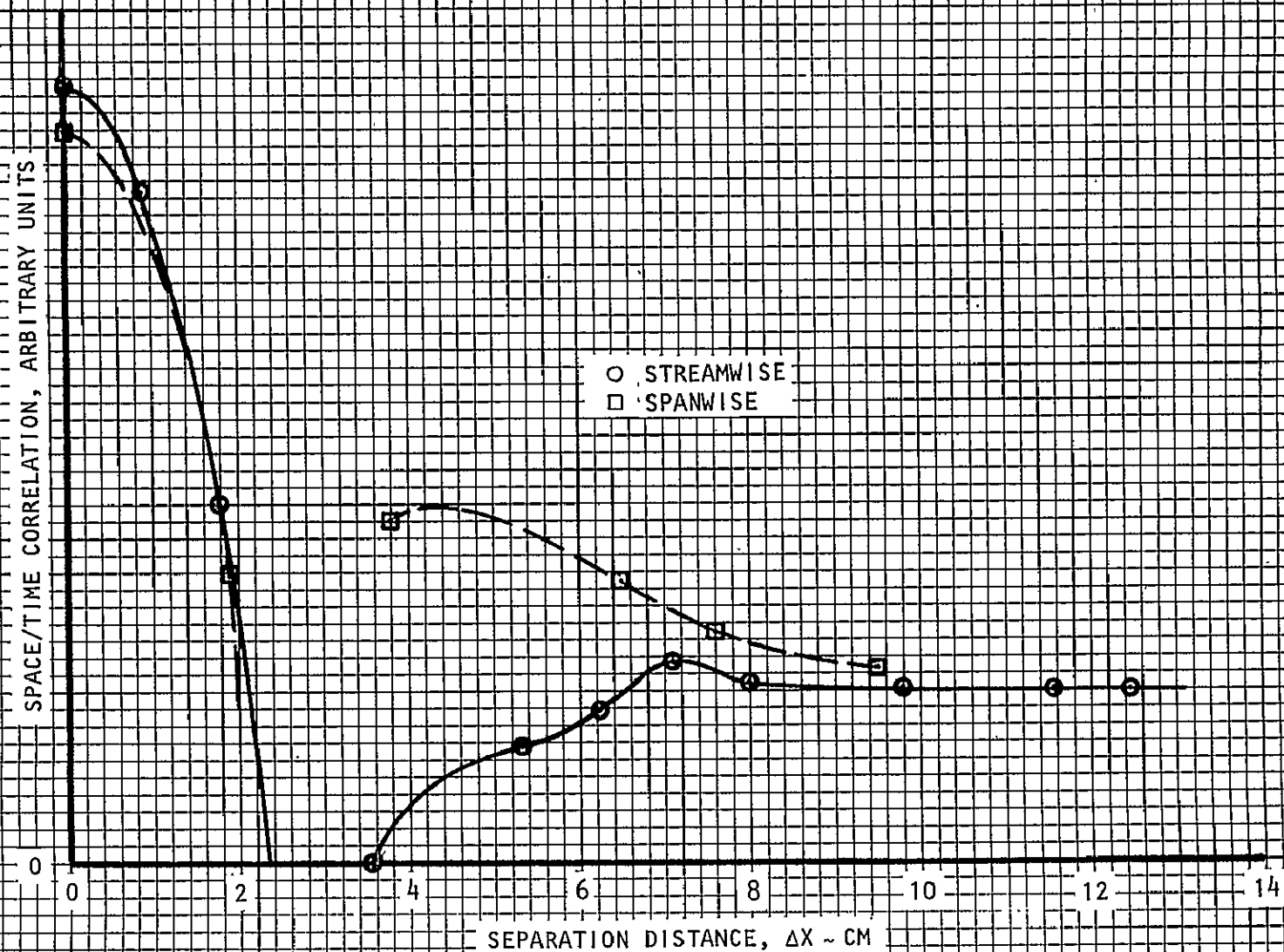


FIGURE 3-31. SPACE/TIME CORRELATION AT ZERO TIME DELAY.

AR-8 NOZZLE; $X_N = 0.2 c$; $\theta_N = 20^\circ$; NPR = 1.1; $R_c = 7.62 \text{ cm}$;
 $\delta_c = 60^\circ$; $L_{jet} = 6.47 \text{ cm}$.

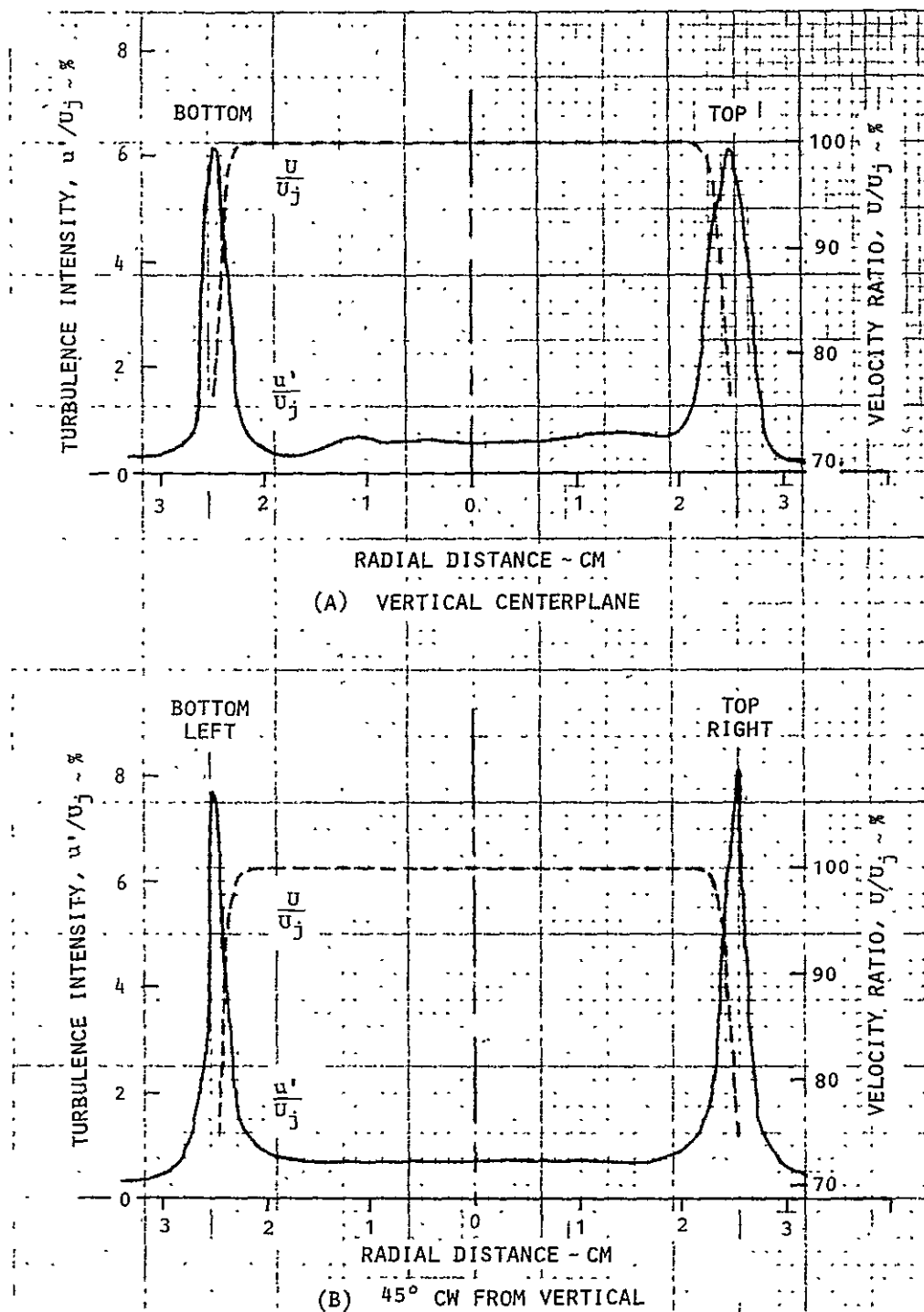


FIGURE 3-32. VELOCITY AND TURBULENCE PROFILES AT LIP OF CIRCULAR NOZZLE.
 $D = 5.08$ CM; $A_N = 20.27$ CM², $NPR = 1.10$.

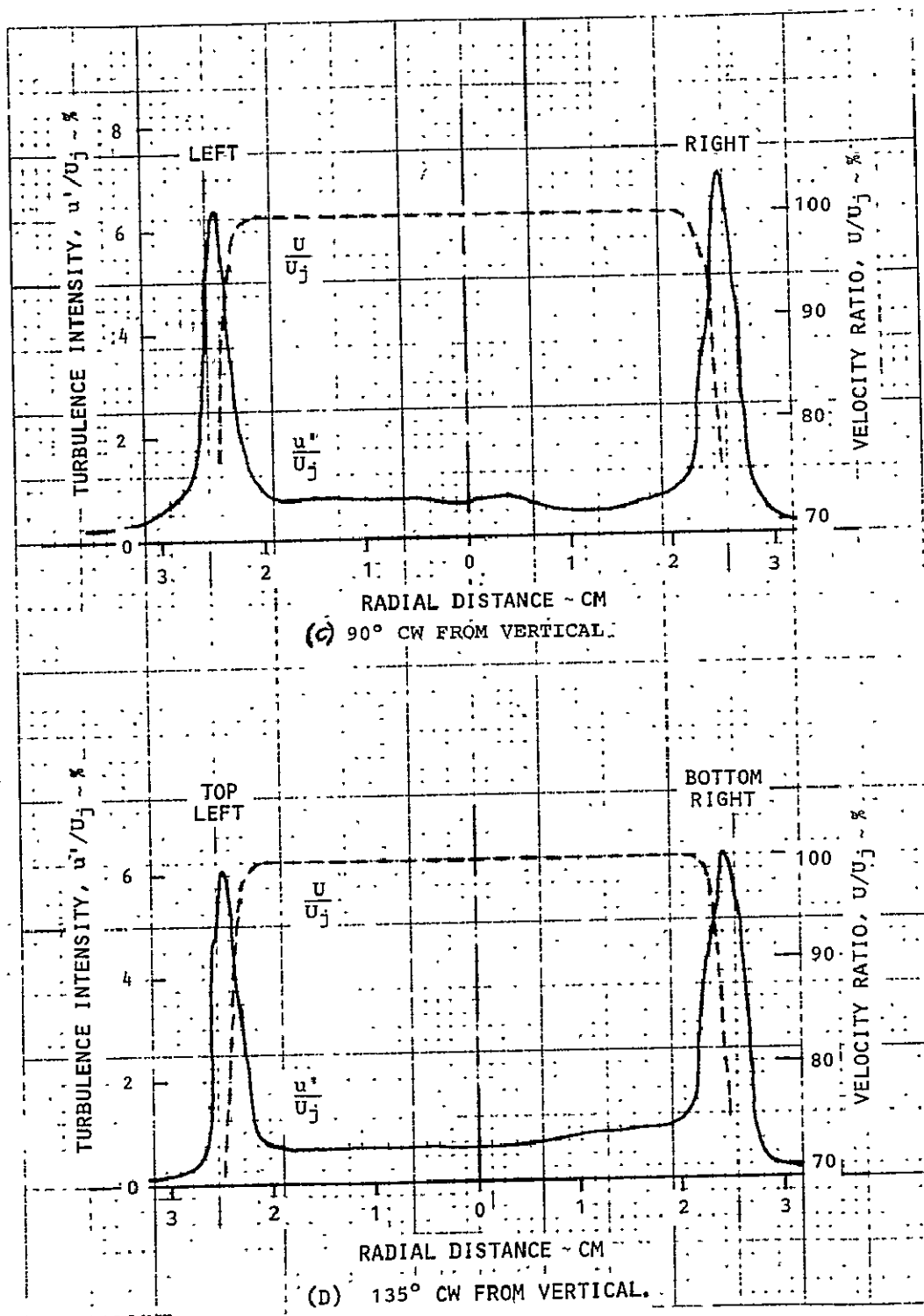


FIGURE 3-32. CONCLUDED.

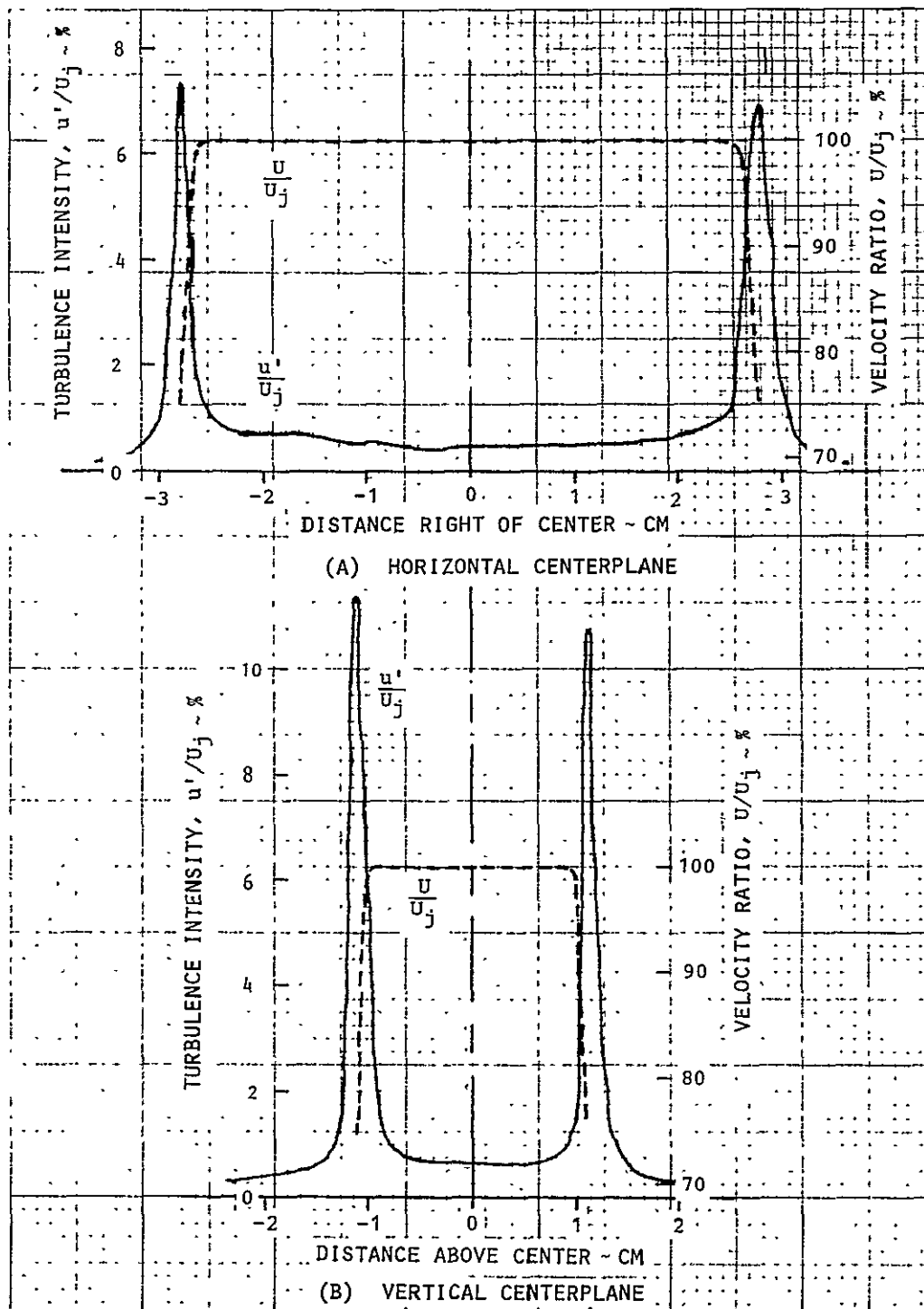
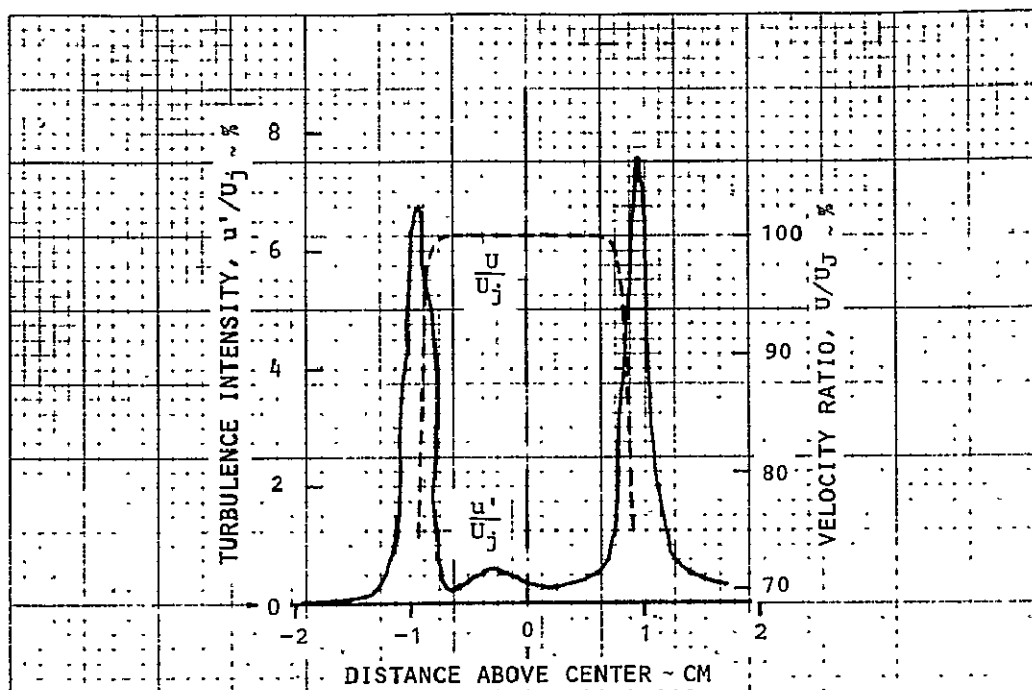
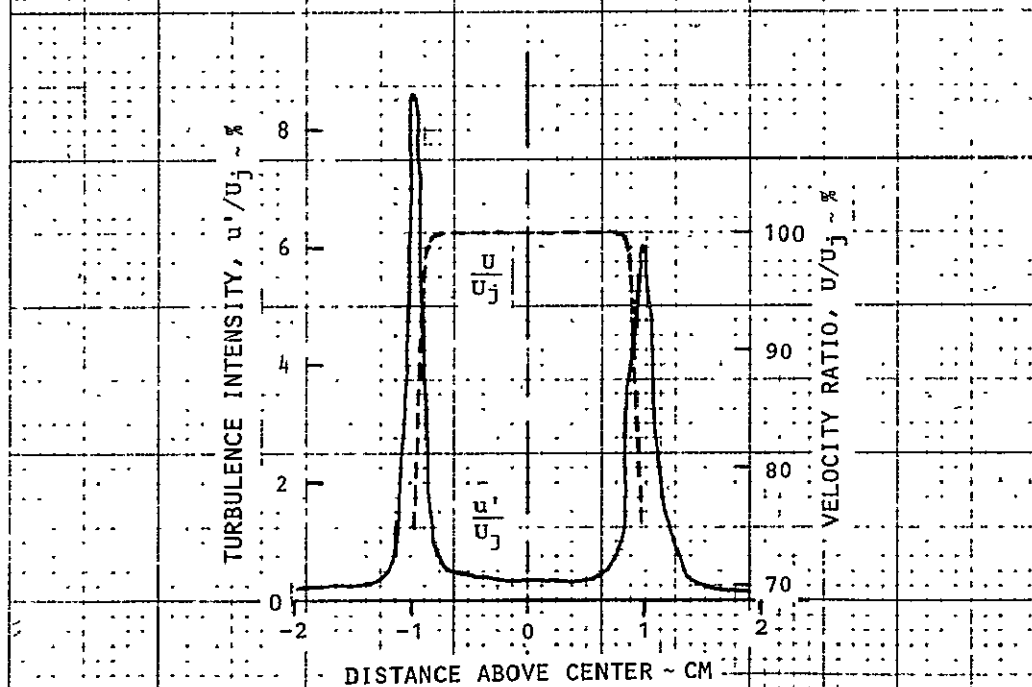


FIGURE 3-33. VELOCITY AND TURBULENCE PROFILES AT LIP OF ELLIPTICAL NOZZLE. 5.74 CM x 2.25 CM; $A_N = 10.13 \text{ CM}^2$; NPR = 1.10.



(C) VERTICAL PLANE 1.27 CM LEFT OF CENTER.



(D) VERTICAL PLANE 1.27 CM RIGHT OF CENTER.

FIGURE 3-33. CONCLUDED.

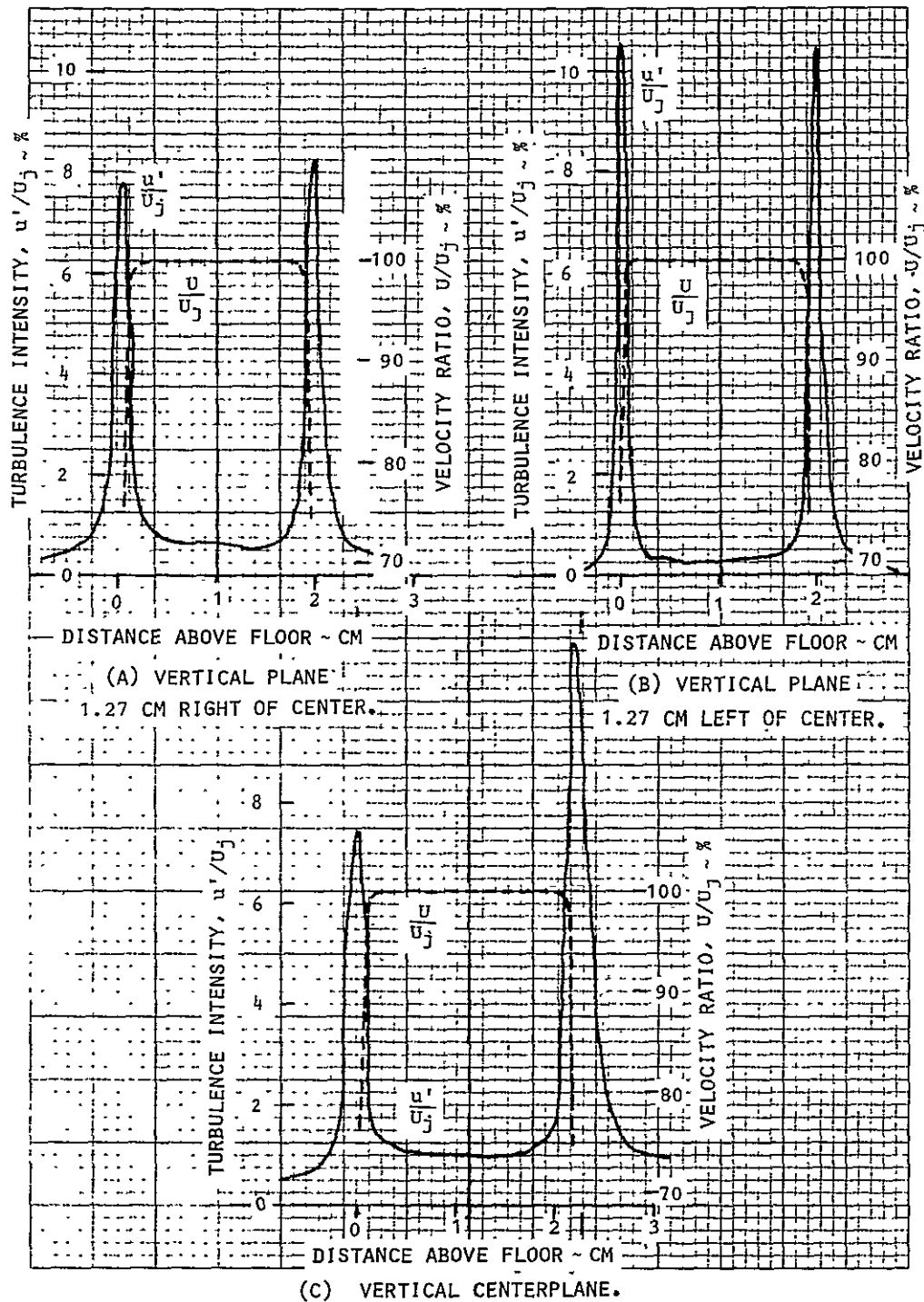
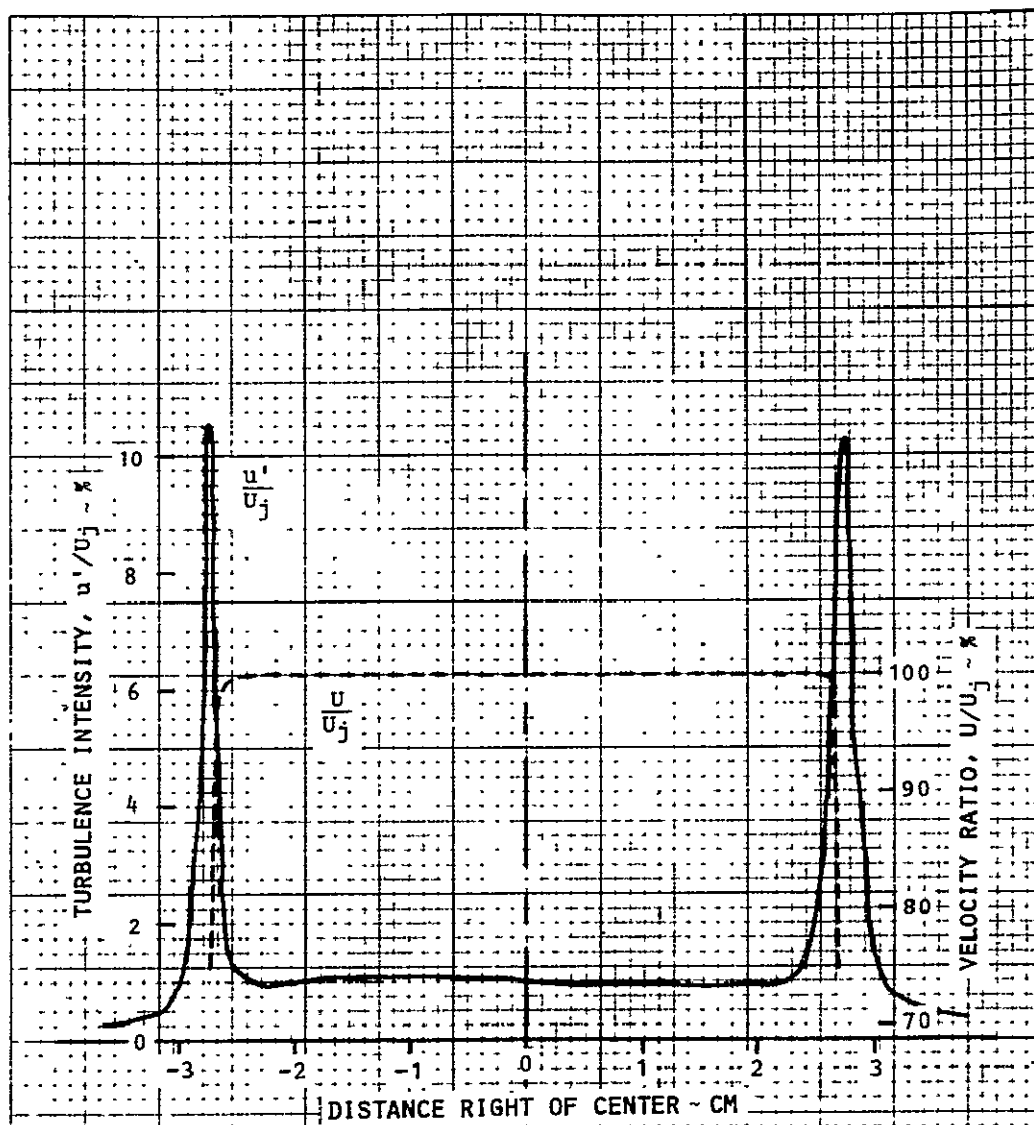


FIGURE 3-34, VELOCITY AND TURBULENCE PROFILES AT LIP OF D NOZZLE.
5.74 CM BY 2.25 CM; $A_N = 10.13 \text{ CM}^2$; NPR = 1.10.



(D) HORIZONTAL PLANE .64 CM ABOVE FLOOR.

FIGURE 3-34, CONCLUDED.

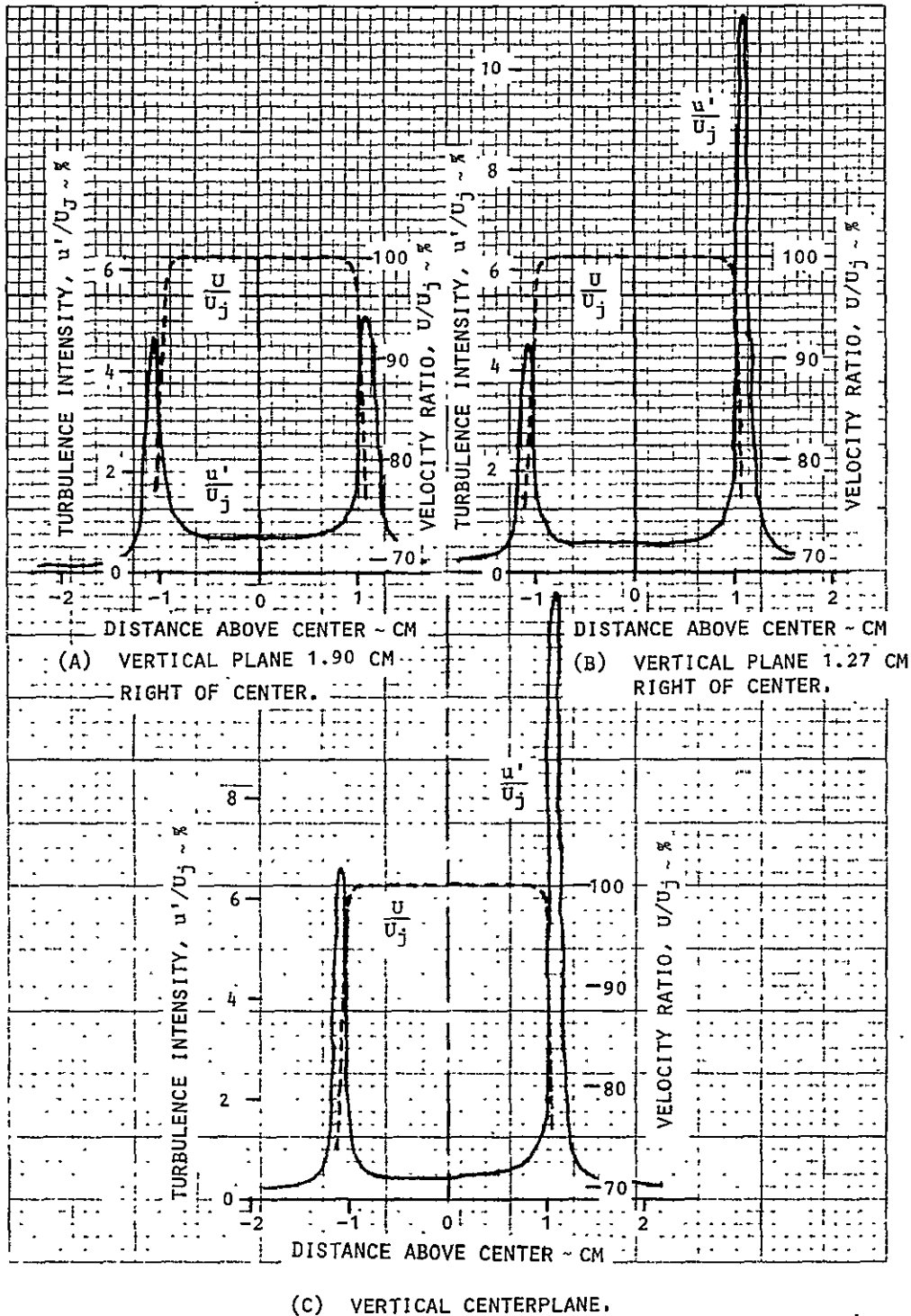
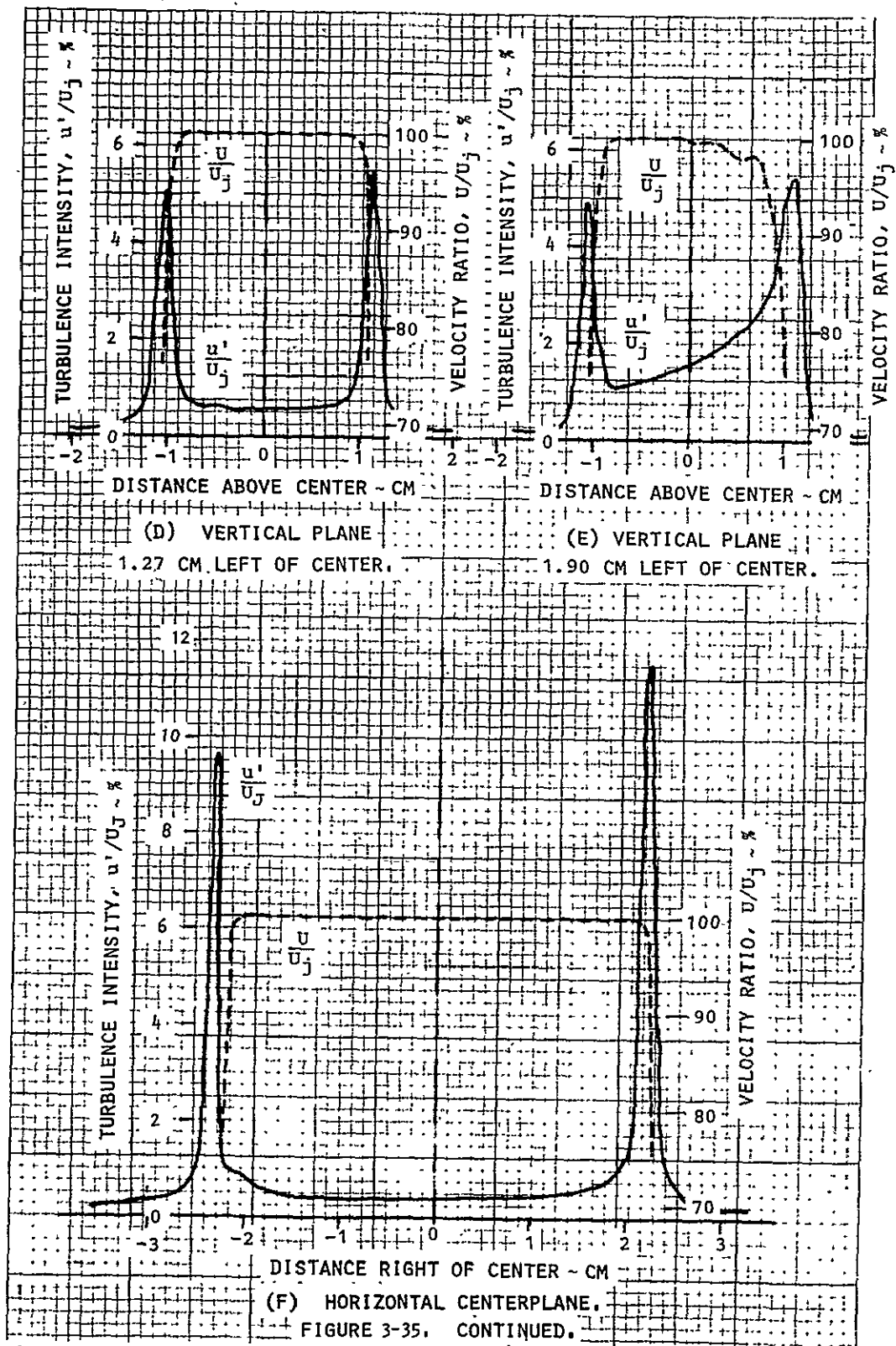
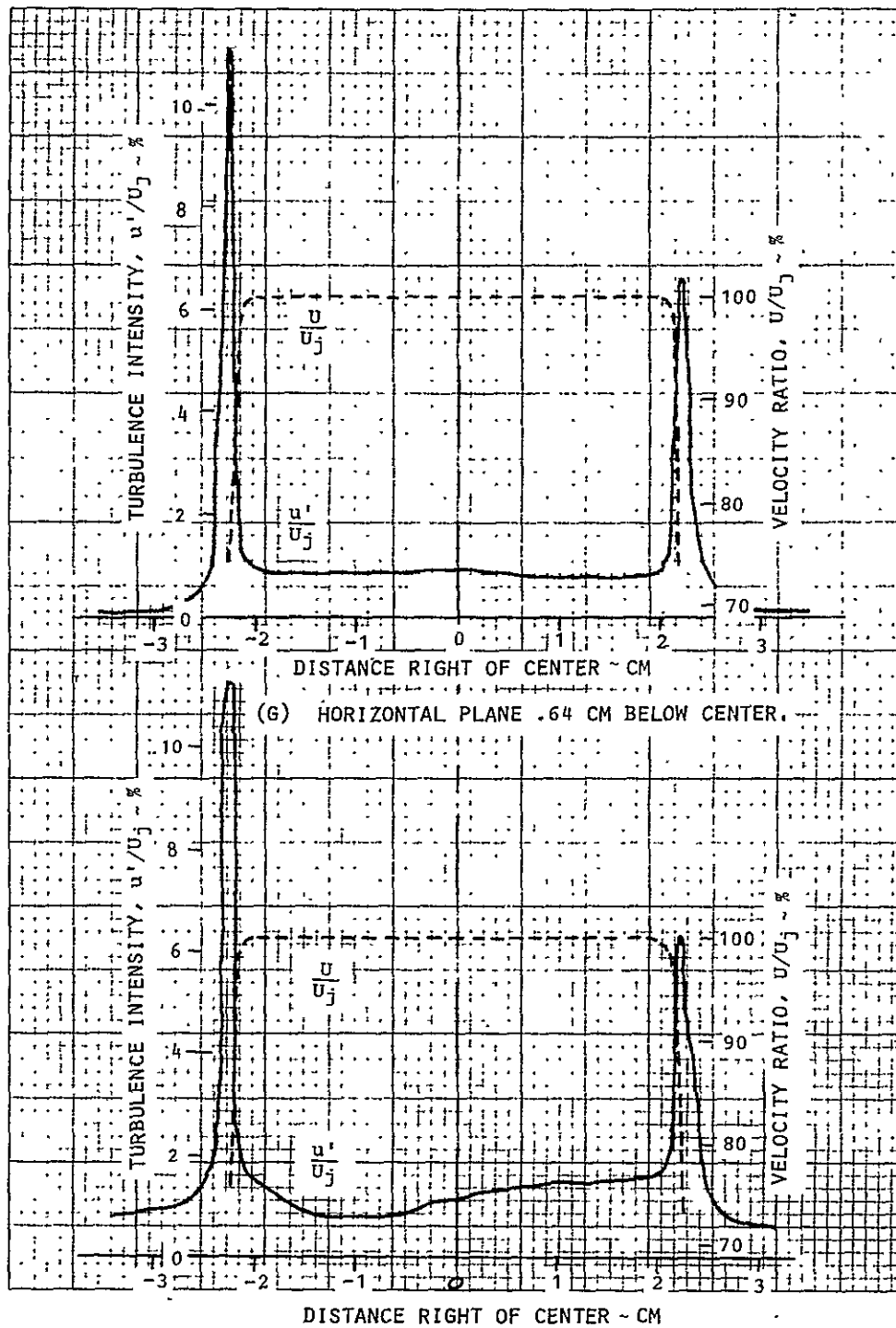


FIGURE 3-35, VELOCITY AND TURBULENCE PROFILES AT LIP OF AR-2 NOZZLE, 4.50 CM BY 2.25 CM; $A_N = 10.13 \text{ CM}^2$; NPR = 1.10.





(H) HORIZONTAL PLANE .64 CM ABOVE CENTER.

FIGURE 3-35, CONCLUDED.

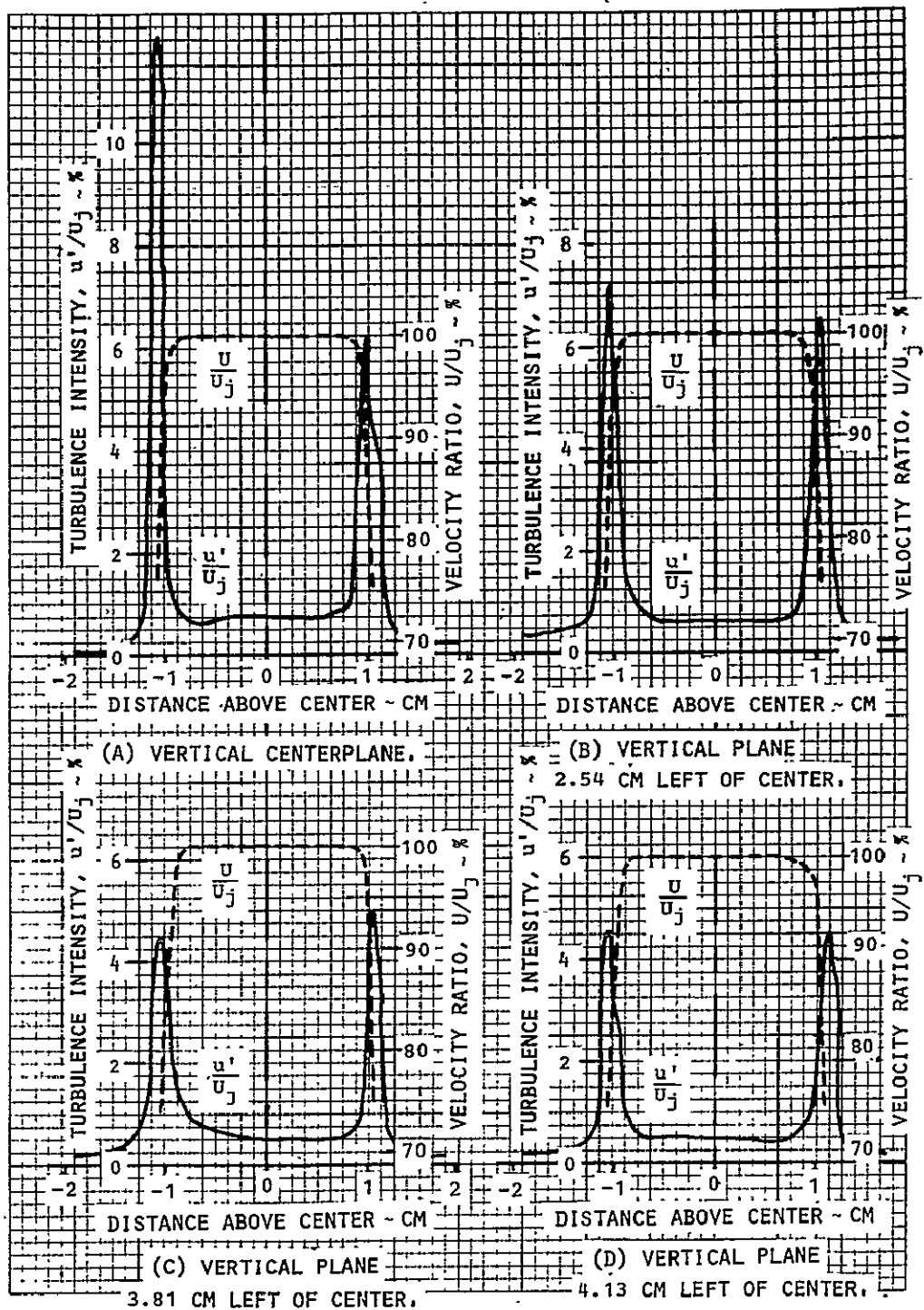
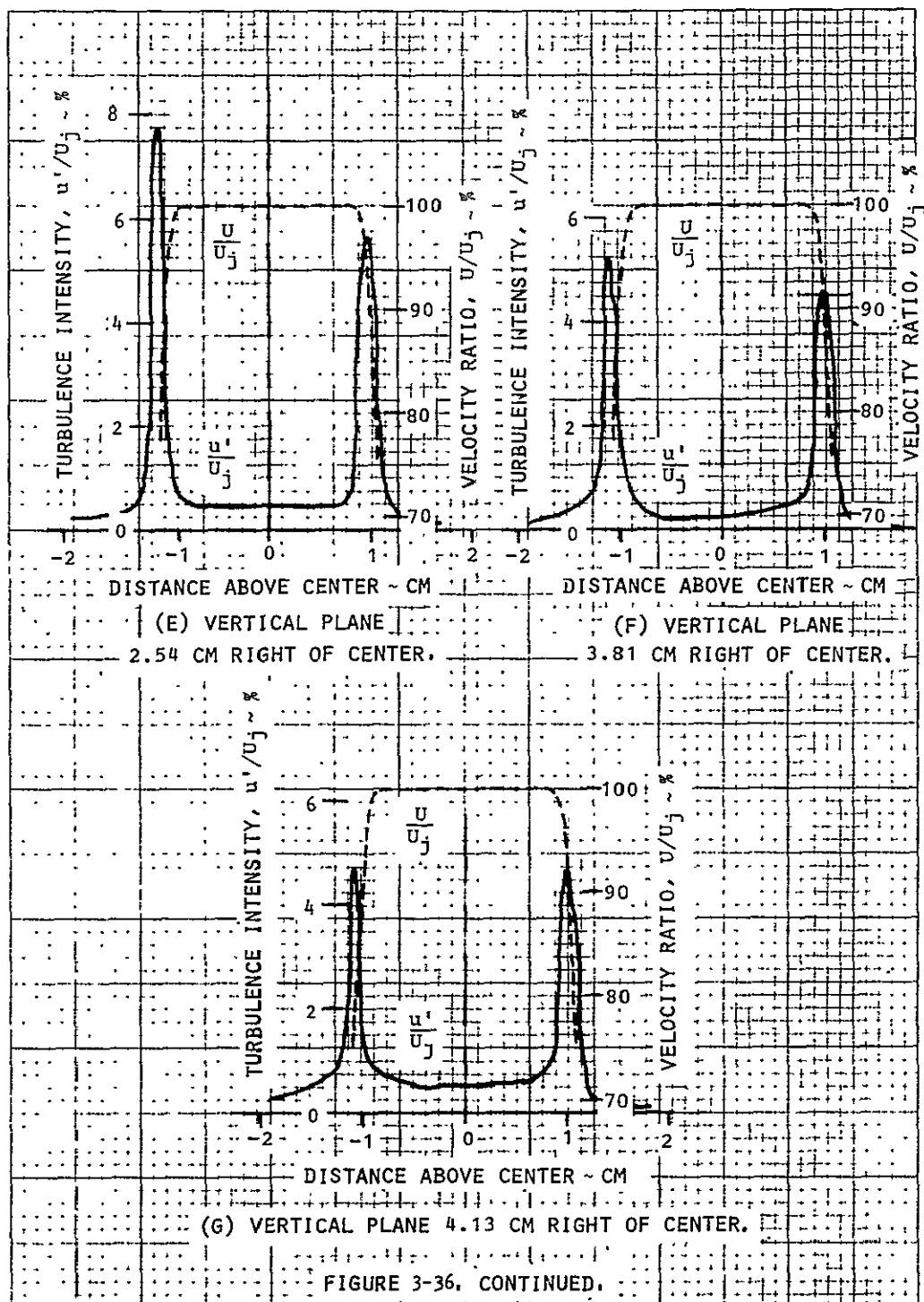


FIGURE 3-36, VELOCITY AND TURBULENCE PROFILES AT LIP OF AR-4 NOZZLE, 9.00 CM BY 2.25 CM; $A_N = 20.27 \text{ CM}^2$; $\text{NPR} = 1.10$.



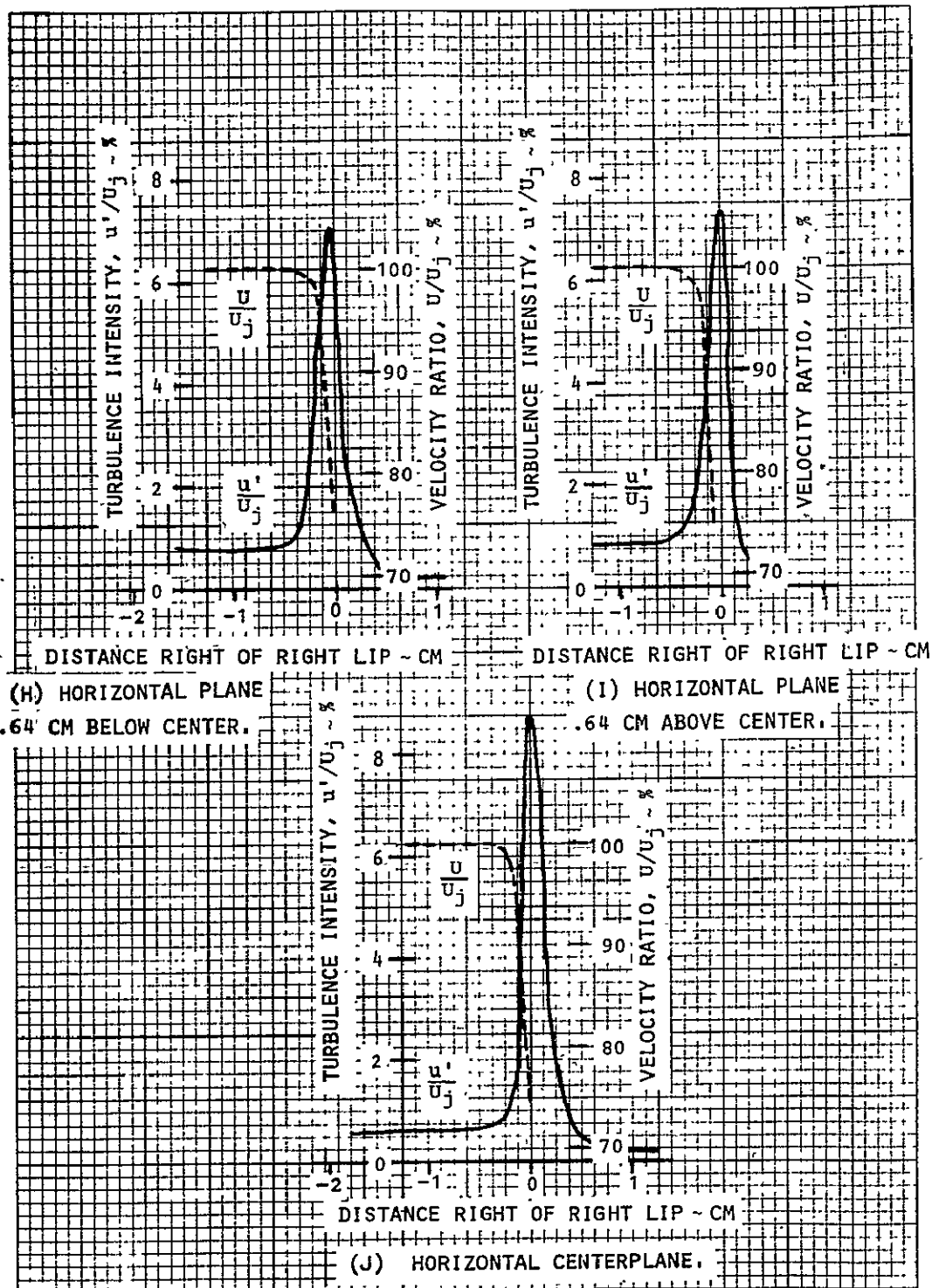


FIGURE 3-36. CONTINUED.

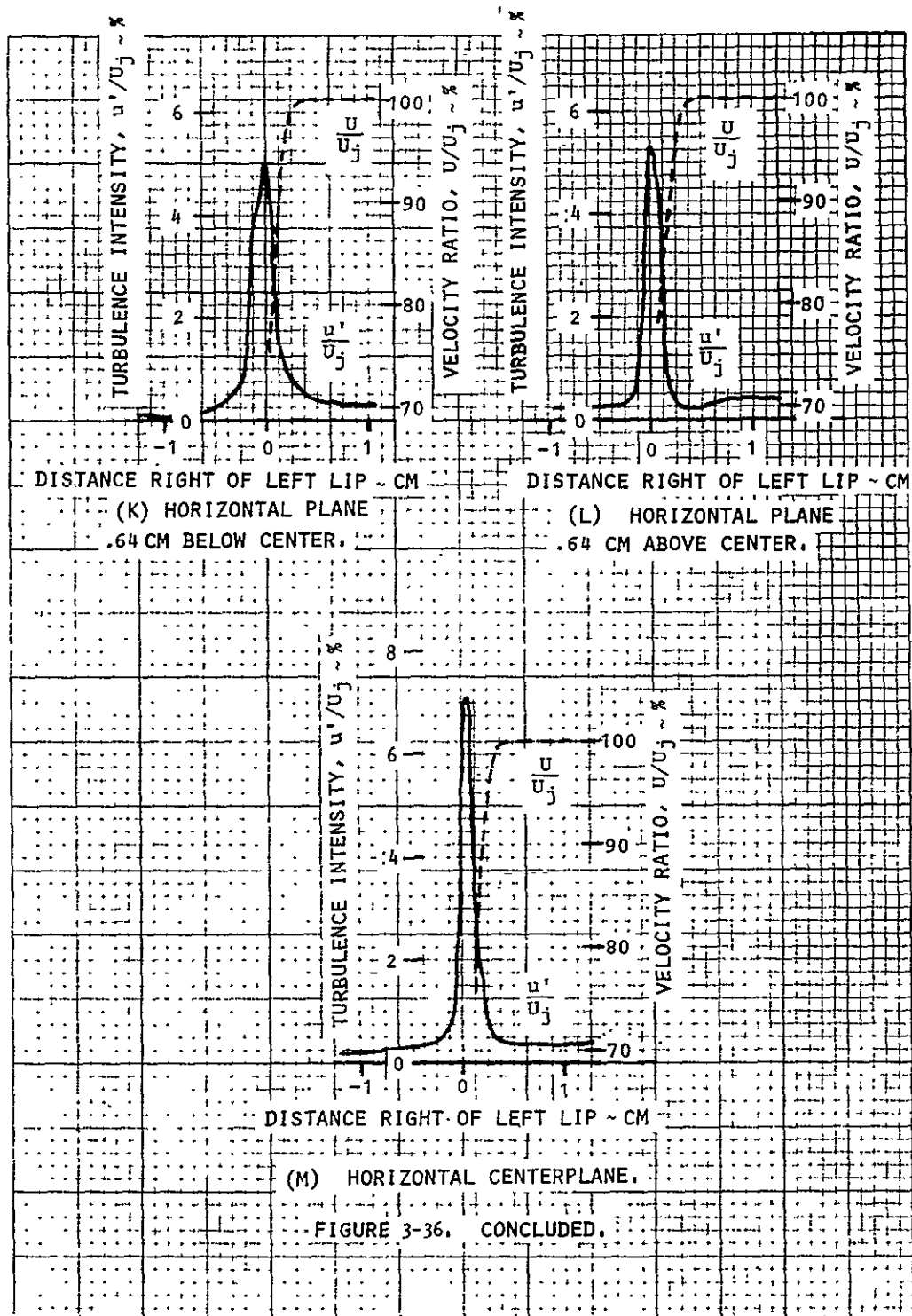


FIGURE 3-36. CONCLUDED.

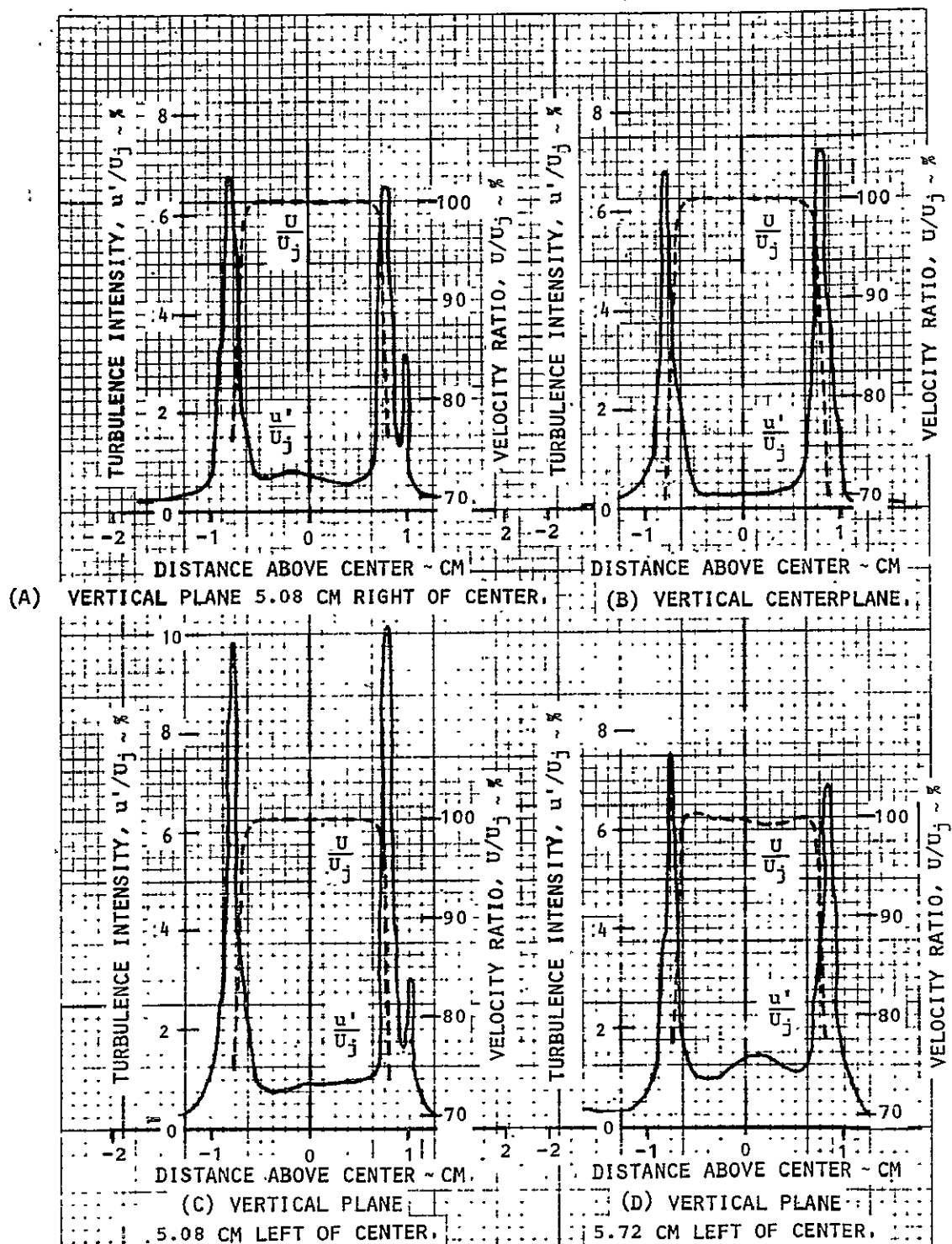
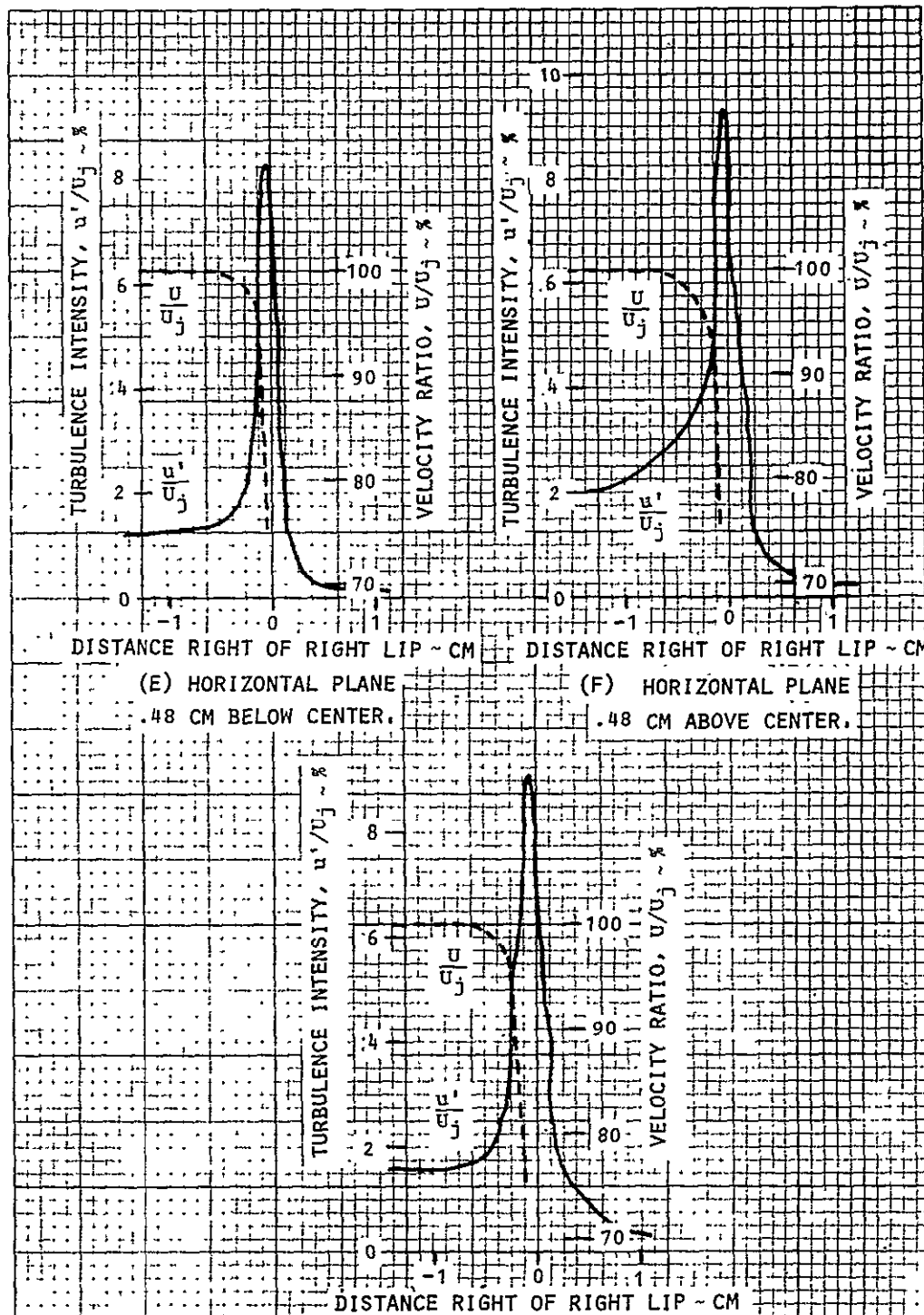


FIGURE 3-37. VELOCITY AND TURBULENCE PROFILES AT LIP OF AR-8 NOZZLE, 12.73 CM BY 1.59 CM; $A_N = 20.27 \text{ cm}^2$; NPR = 1.10.



(G) HORIZONTAL CENTERPLANE,
FIGURE 3-37. CONTINUED,

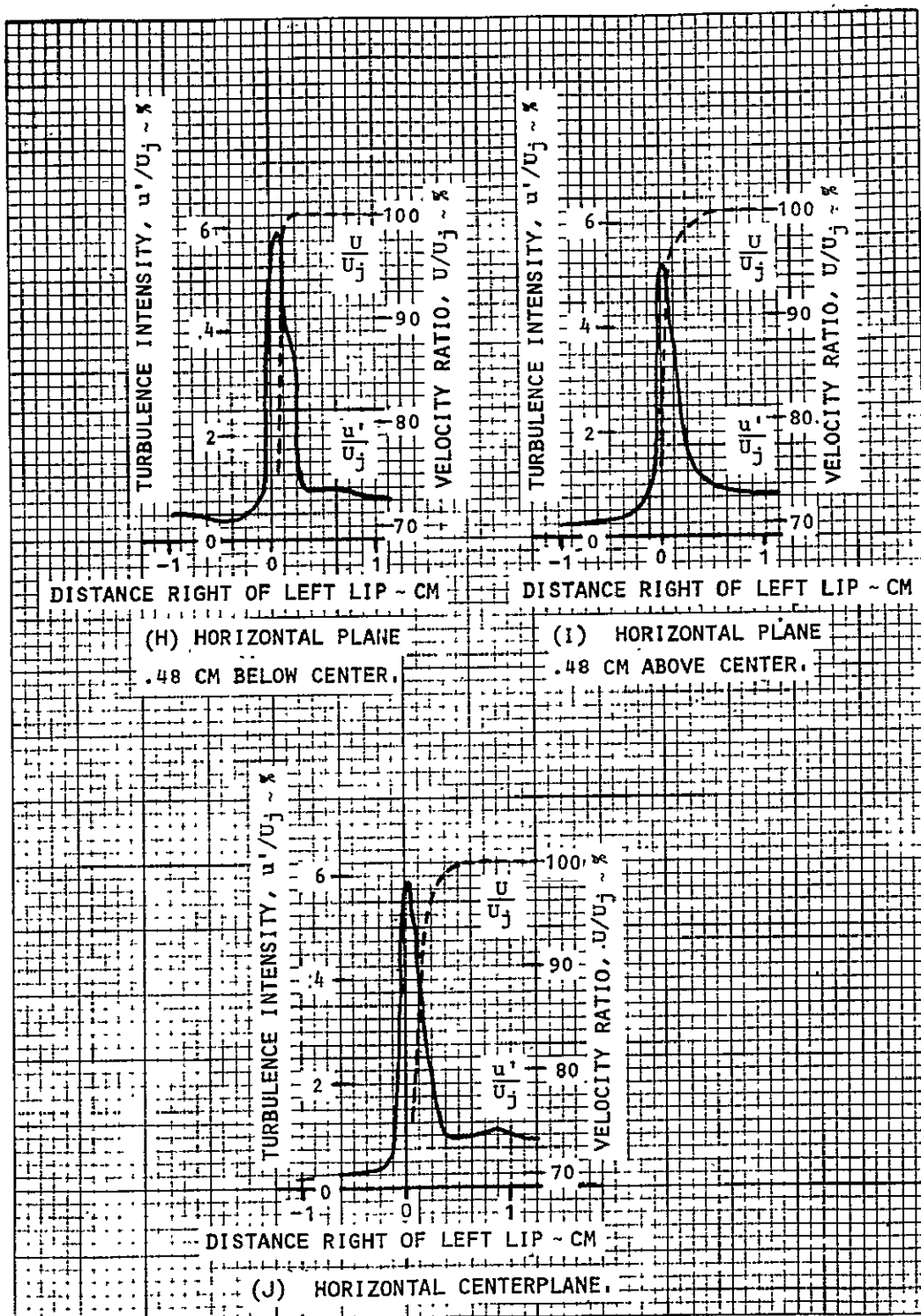


FIGURE 3-37. CONCLUDED.

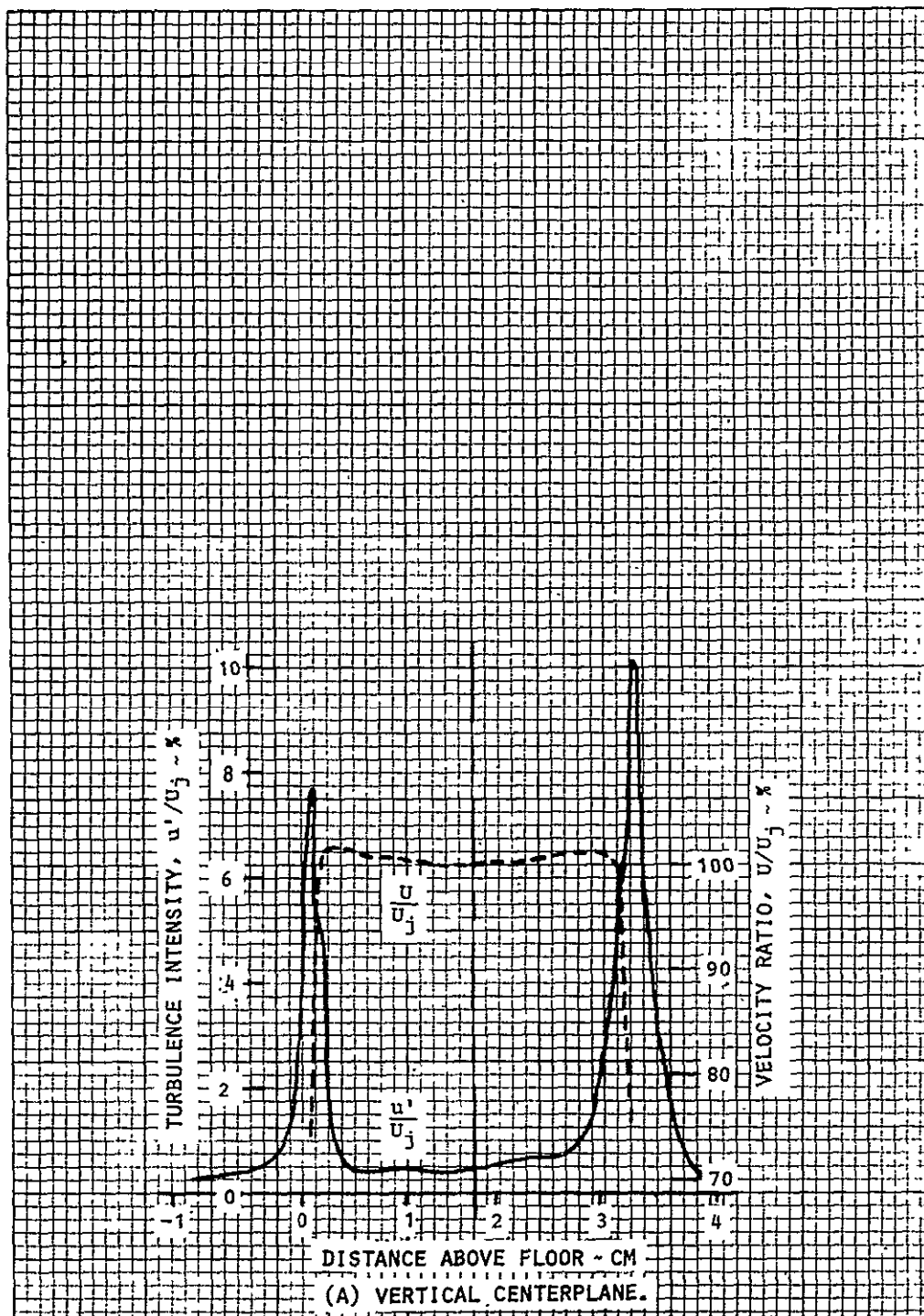
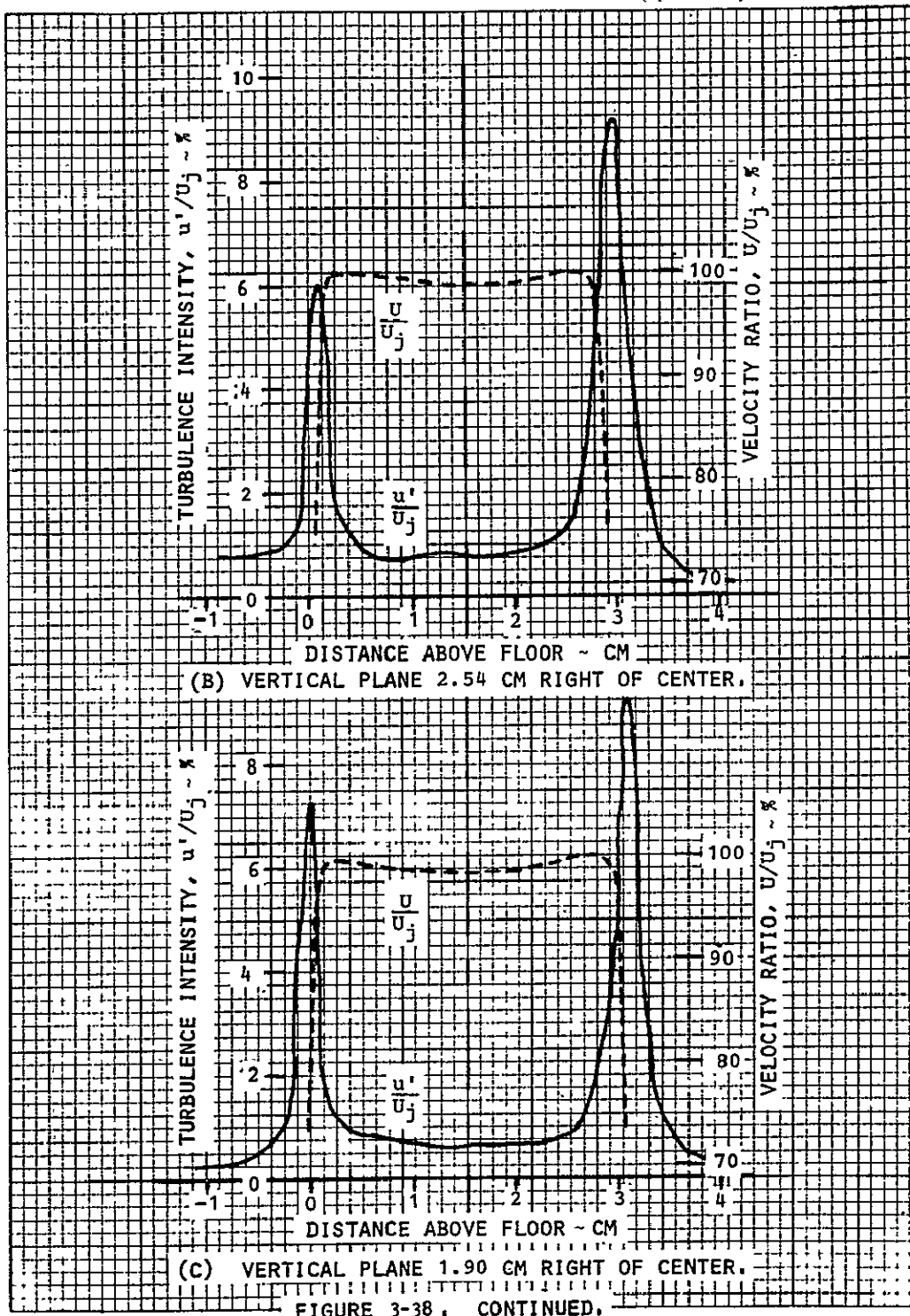


FIGURE 3-38, VELOCITY AND TURBULENCE PROFILES AT LIP OF QCSEE NOZZLE.
 $A_N = 29.29 \text{ CM}^2$; $\text{NPR} = 1.10$.



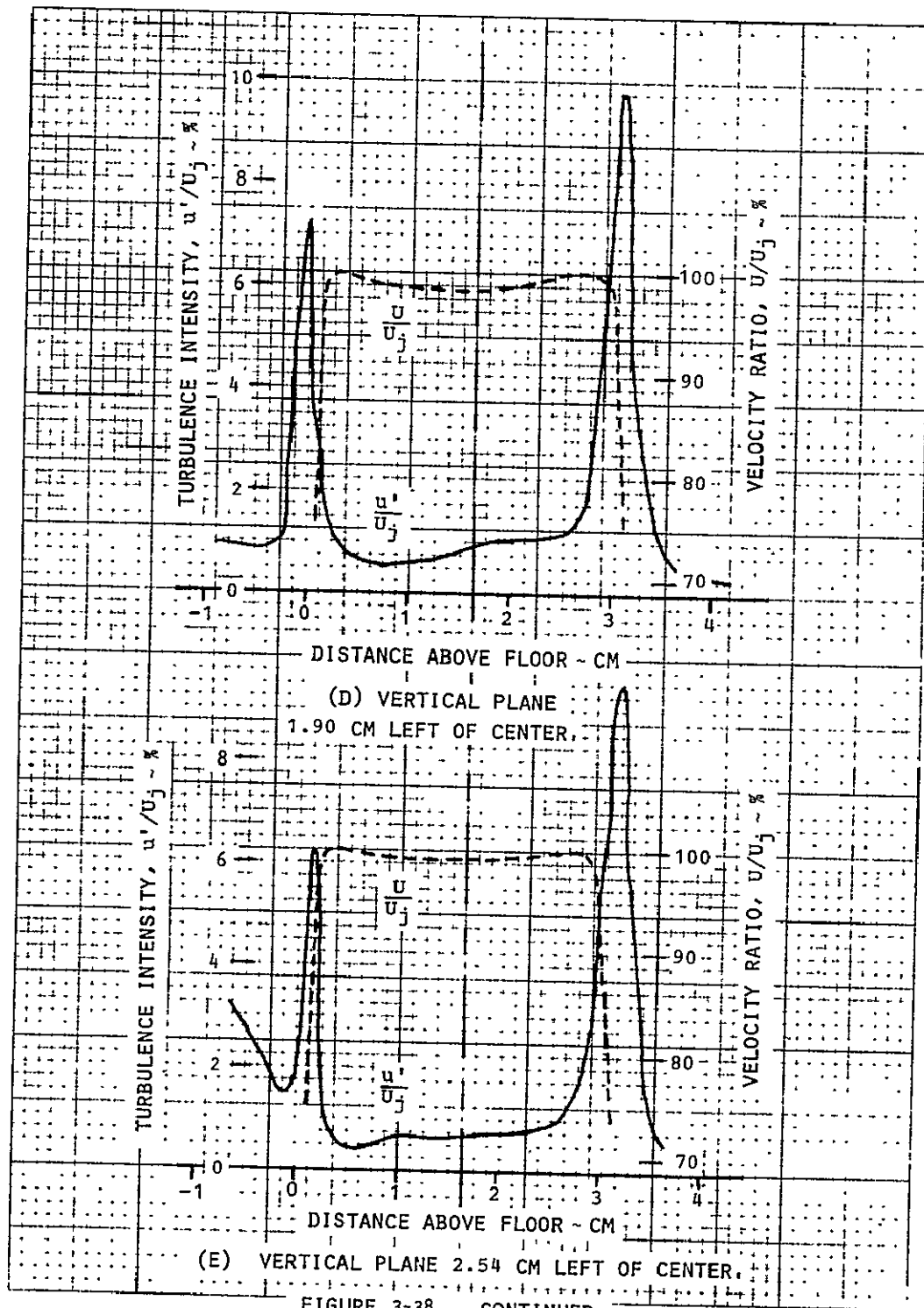
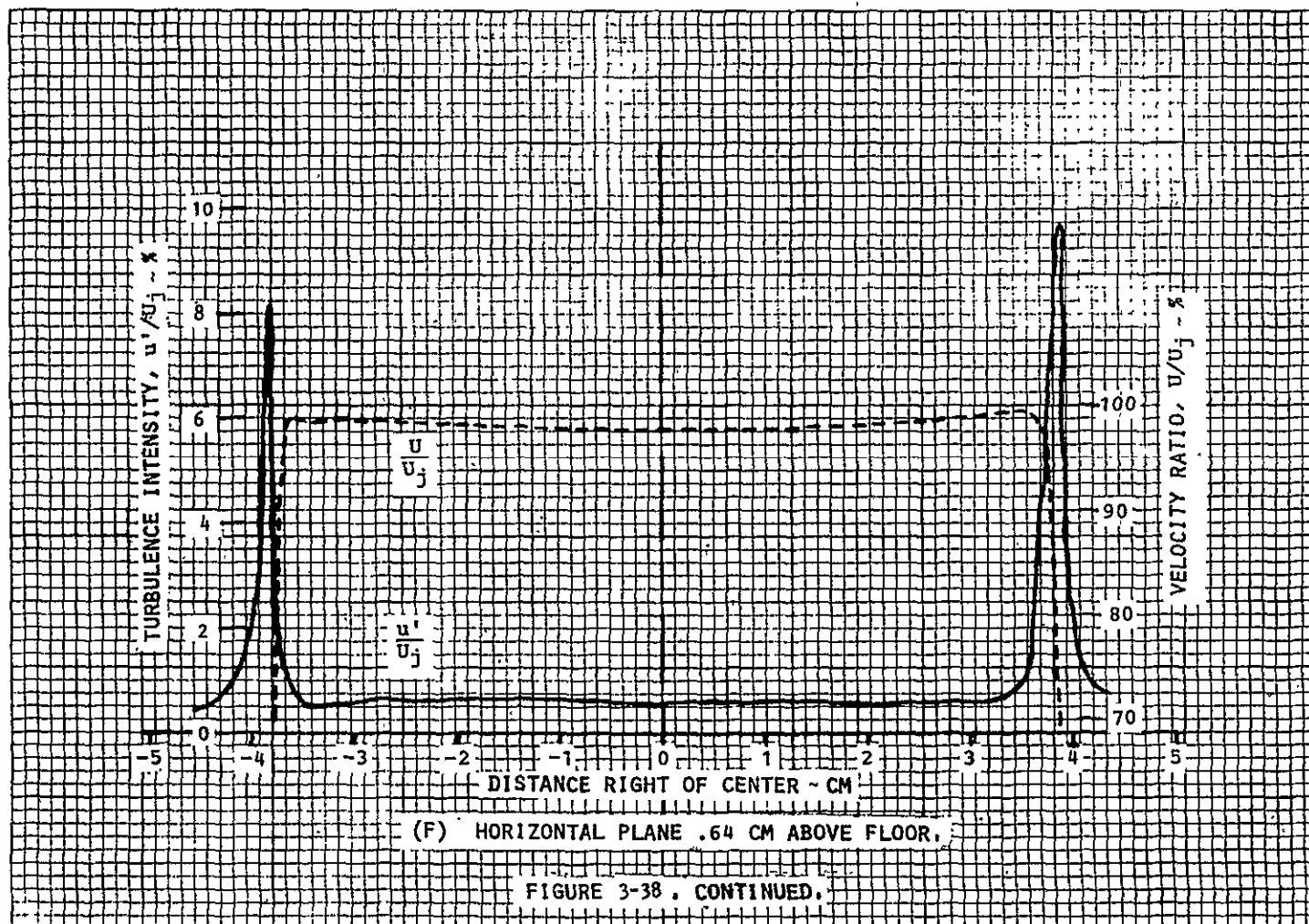
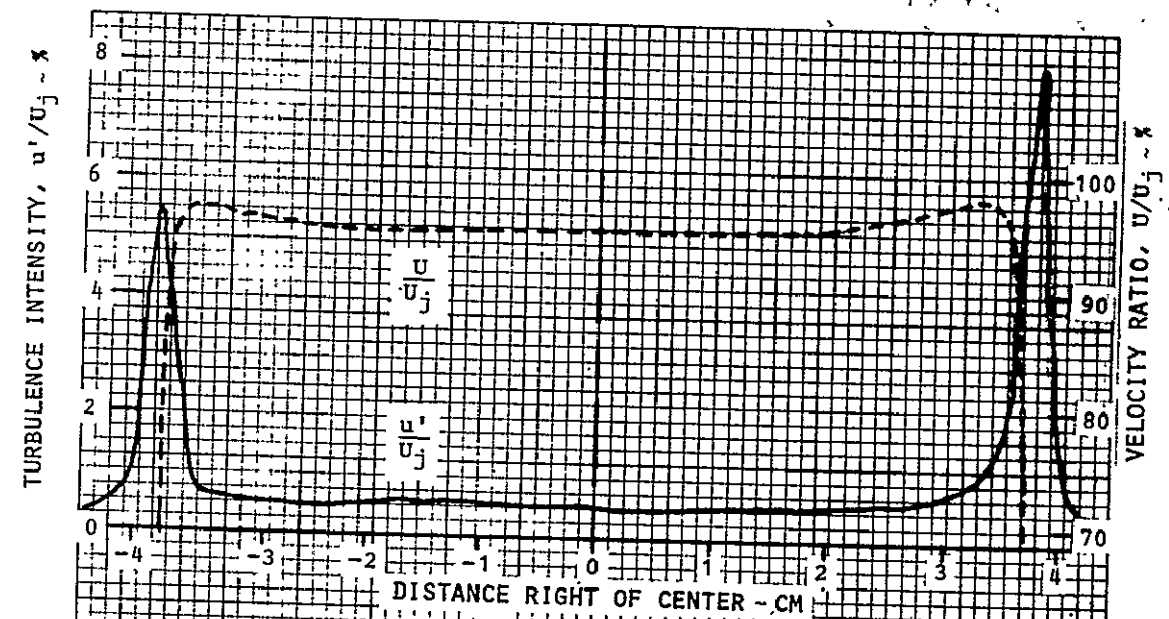
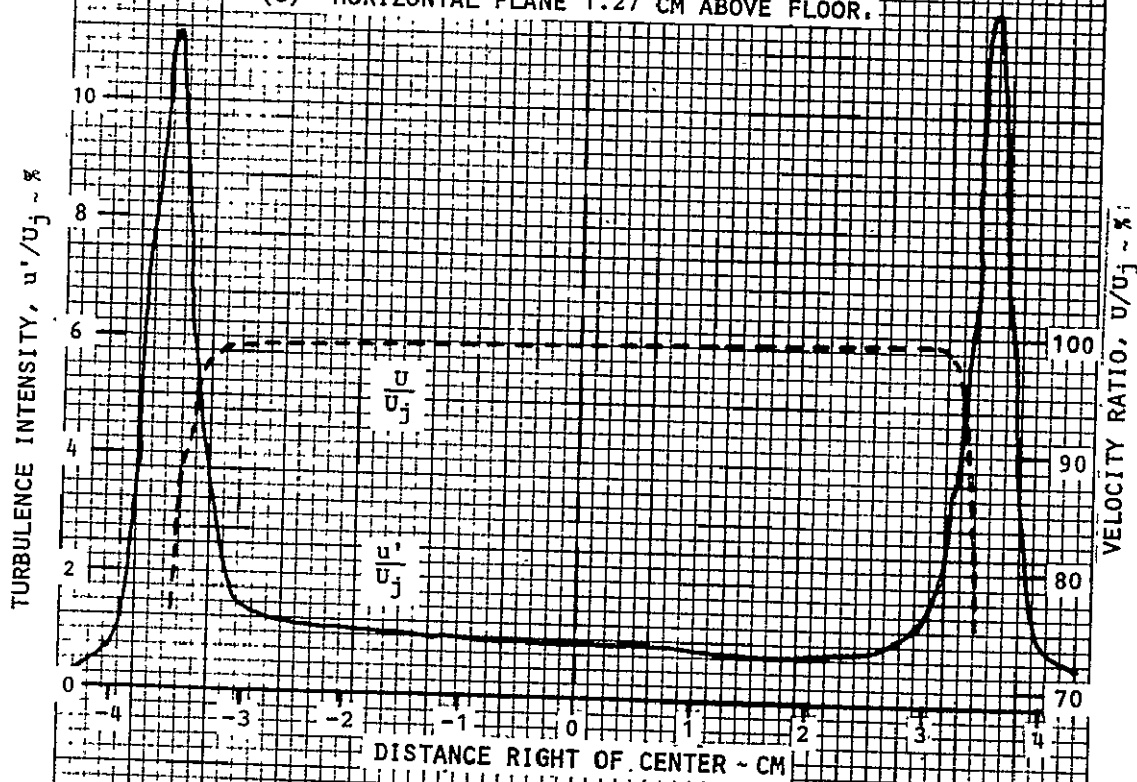


FIGURE 3-38. CONTINUED.





(G) HORIZONTAL PLANE 1.27 CM ABOVE FLOOR.



(H) HORIZONTAL PLANE 2.54 CM ABOVE FLOOR.

FIGURE 3-38, CONTINUED.

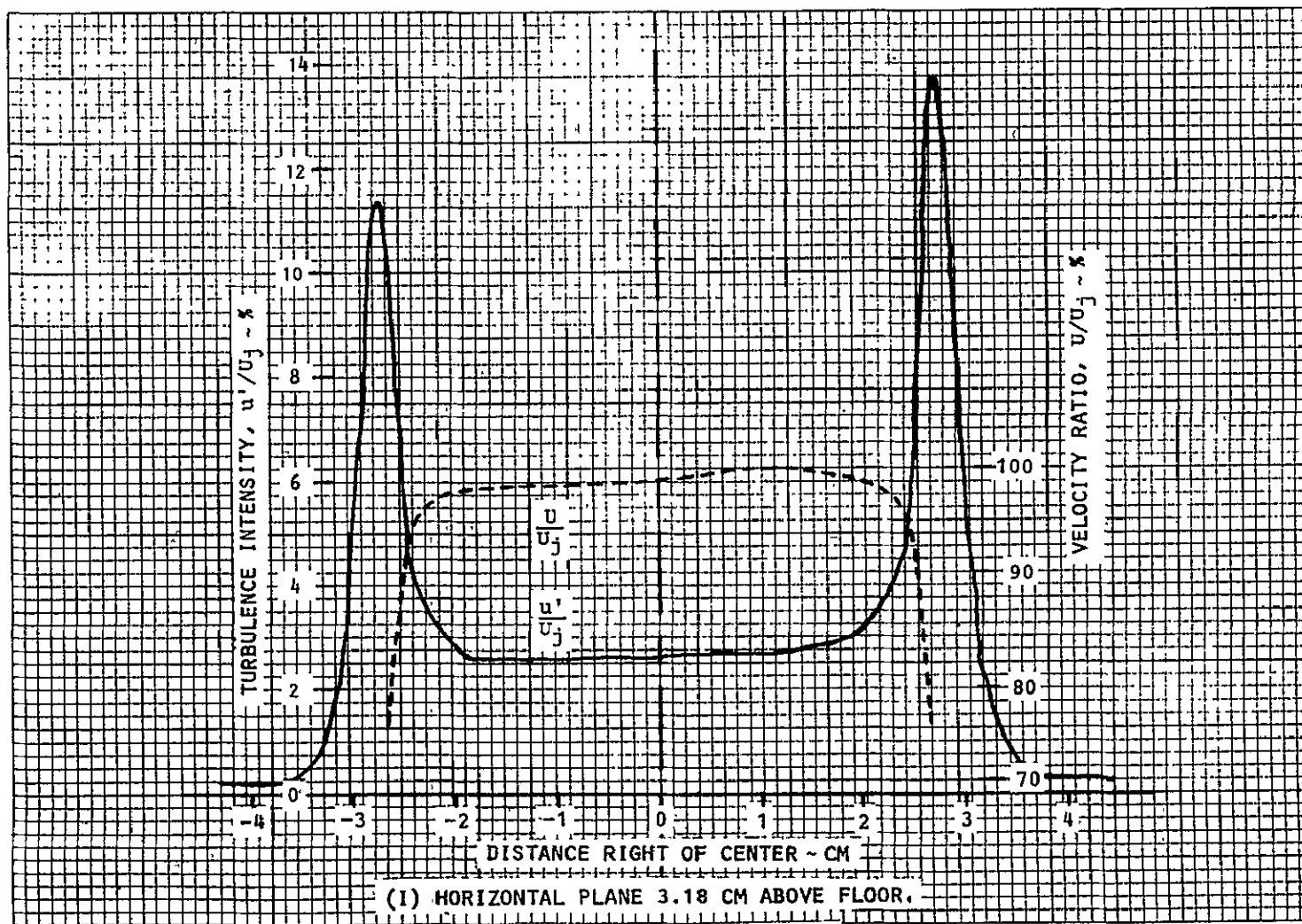


FIGURE 3-38. CONCLUDED.

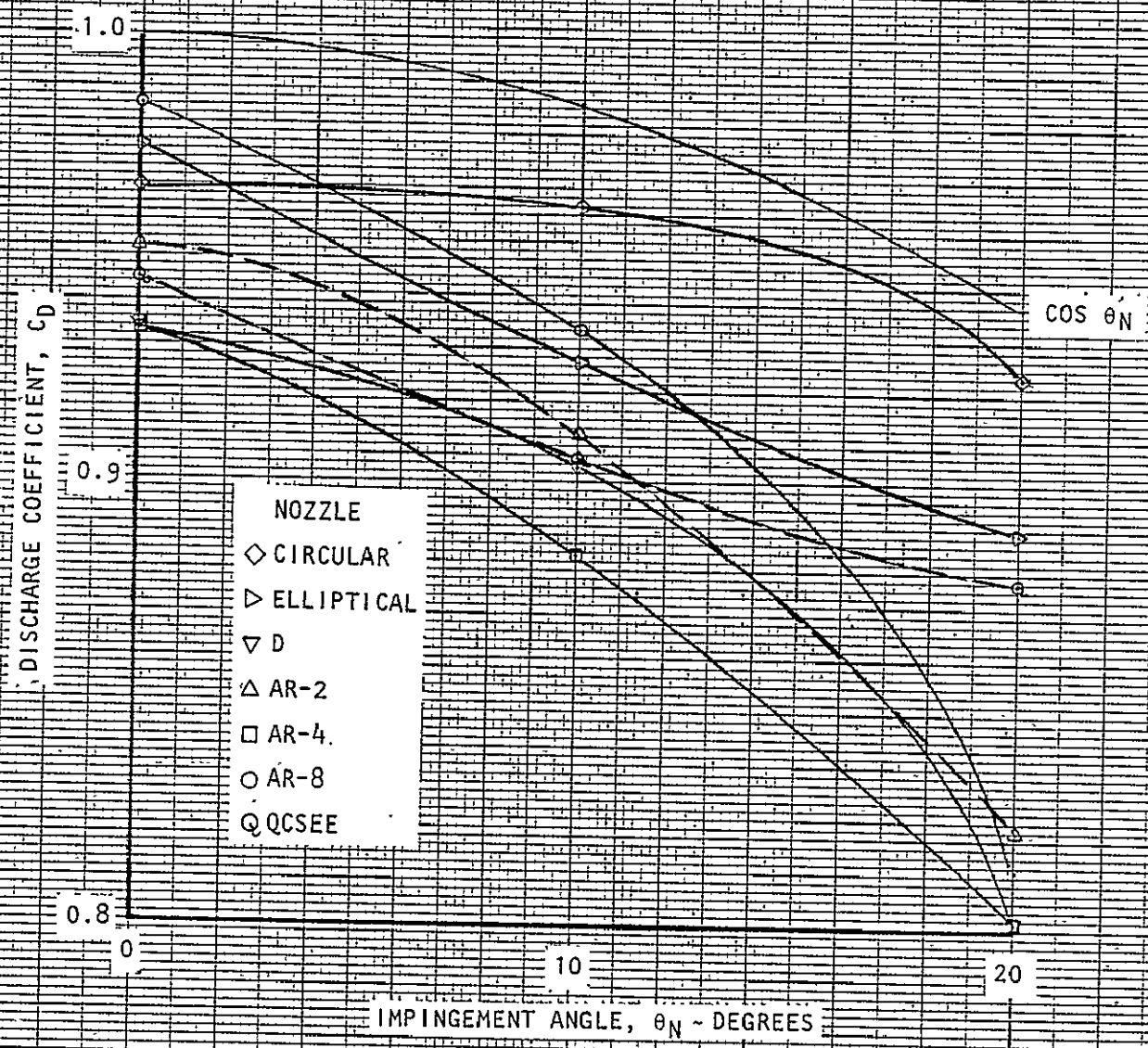
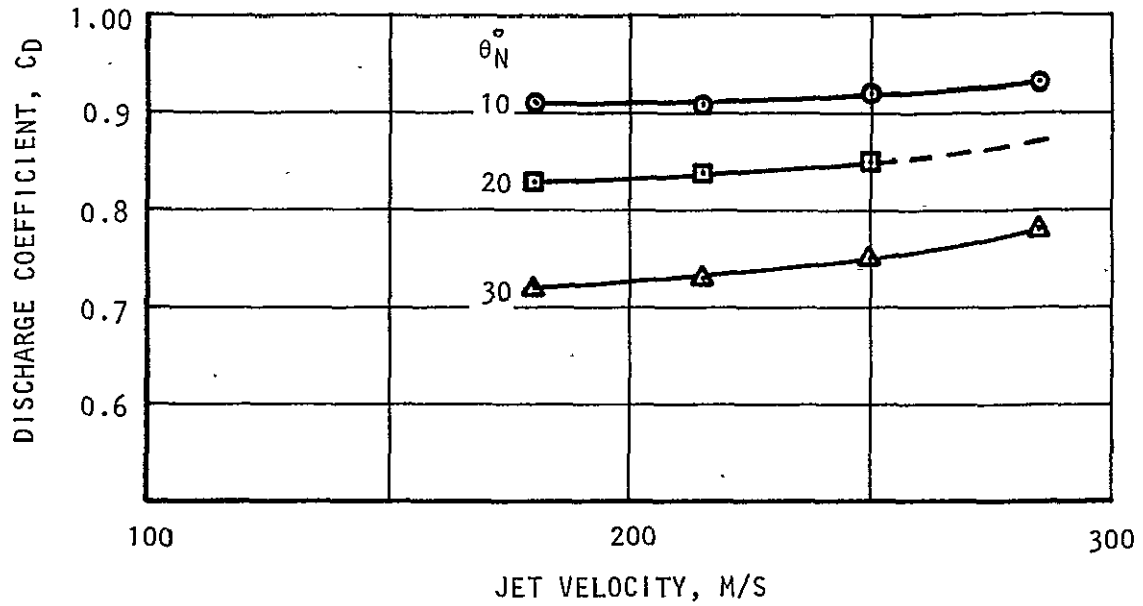
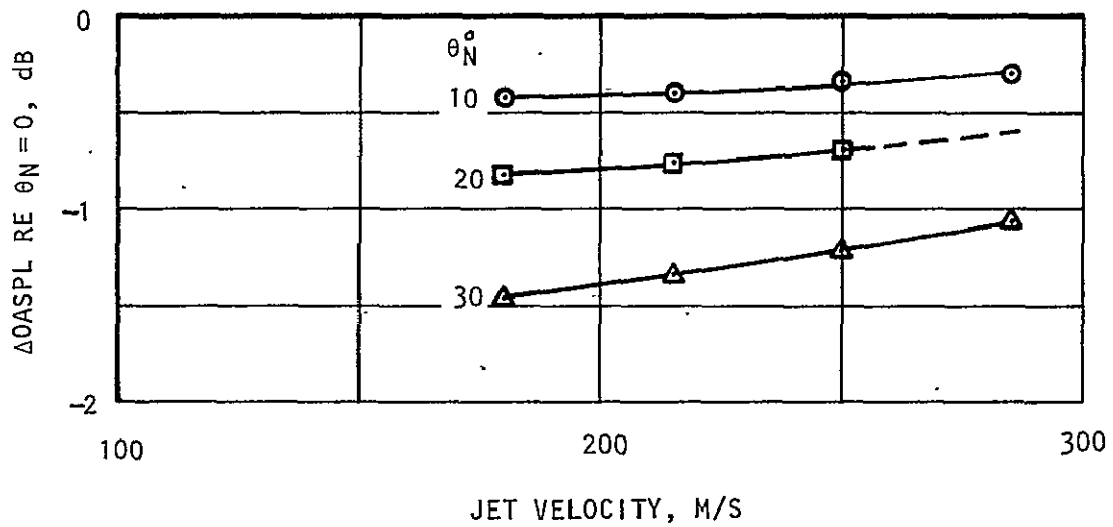


FIGURE 3-39. EFFECT OF IMPINGEMENT ANGLE ON DISCHARGE COEFFICIENT.



(A) MASS FLOW.



(B) NOISE.

FIGURE 3-40. EFFECT OF IMPINGEMENT ANGLE ON MASS FLOW AND NOISE.

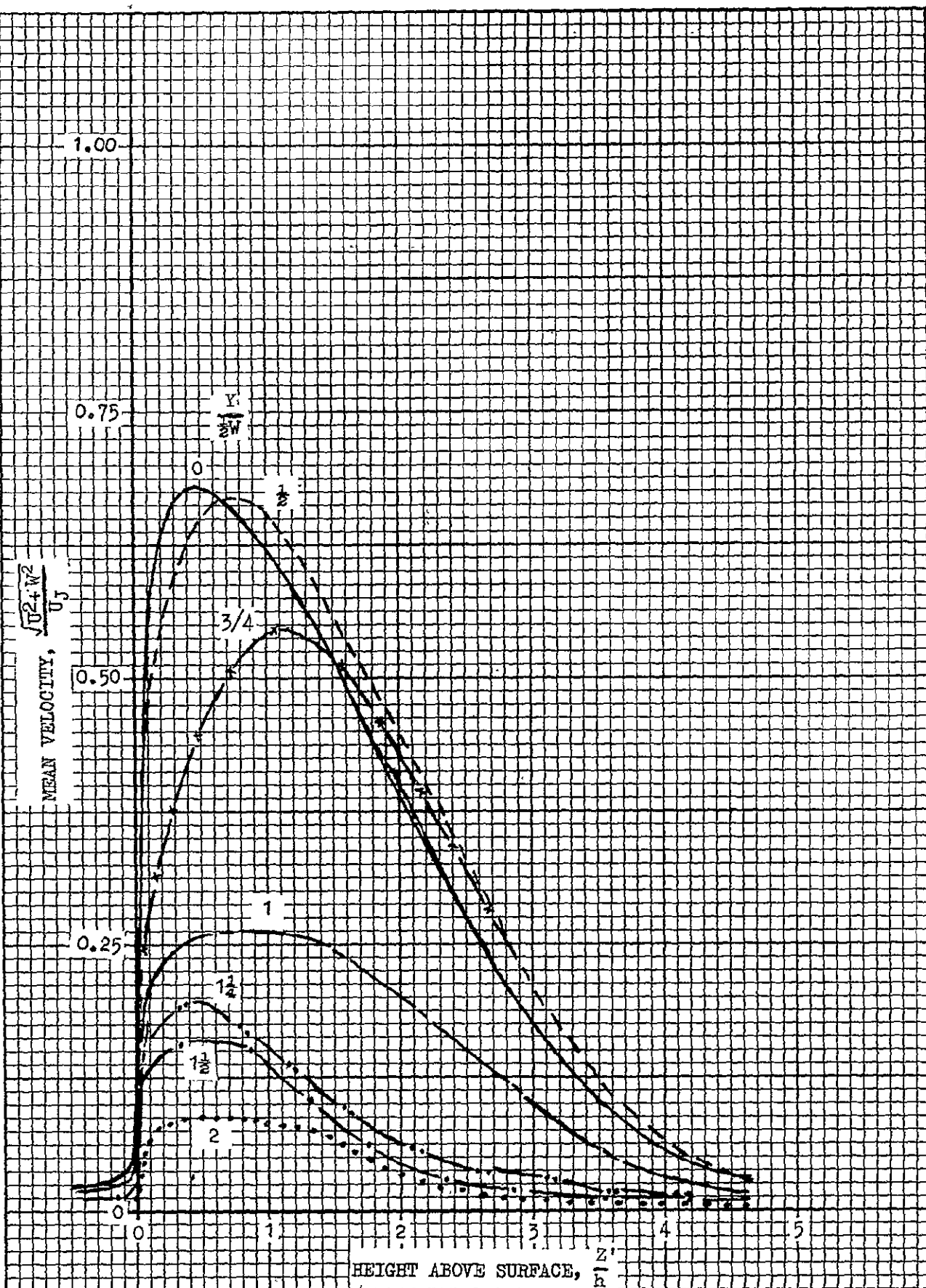


FIGURE 3-41. TRAILING EDGE MEAN VELOCITY PROFILES--N1 NOZZLE

AR = 8 RECTANGULAR, $h = 1.59$ cm (0.625 in),
 $W = 12.7$ cm (5.0 in), NPR = 1.1

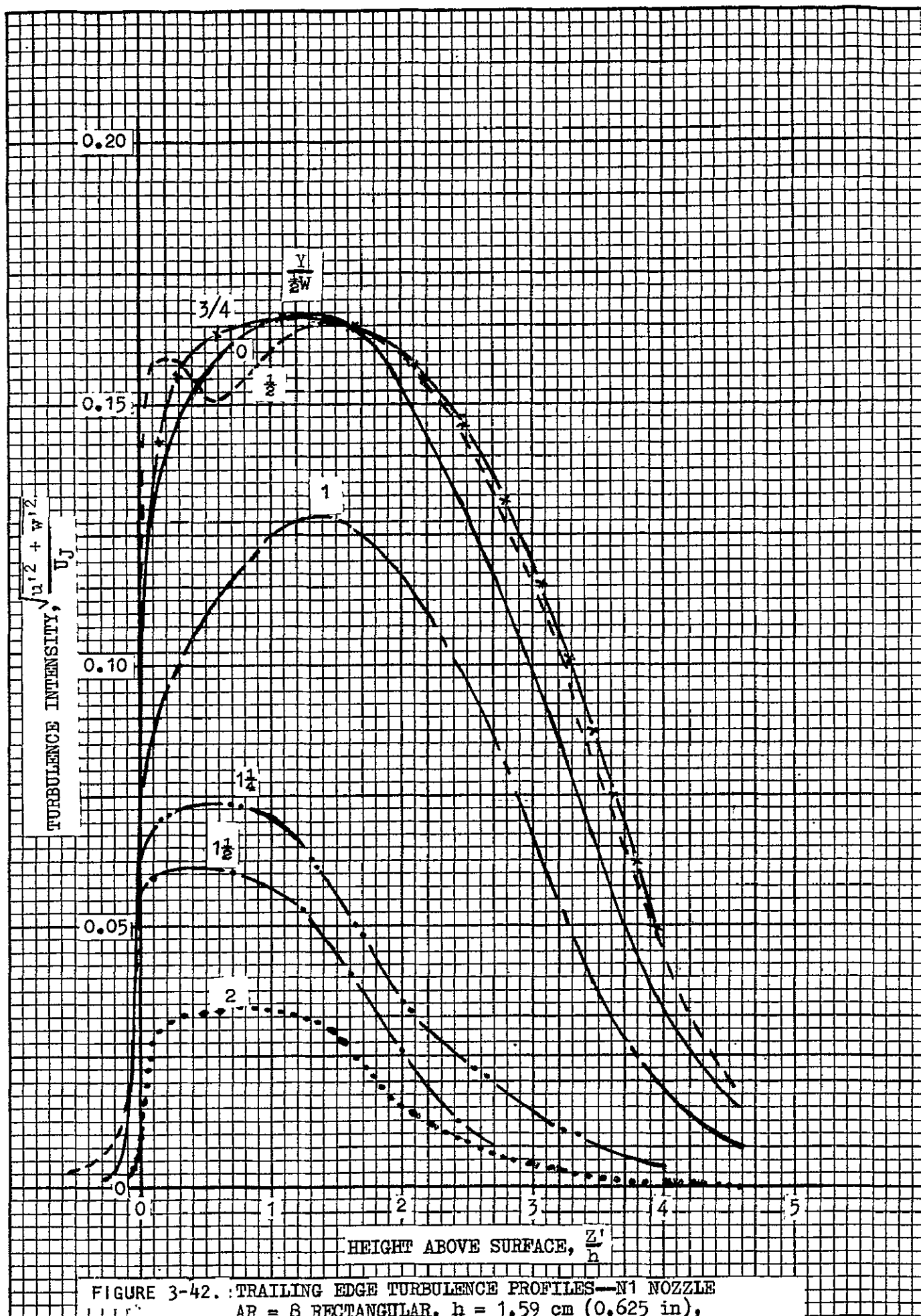


FIGURE 3-42. TRAILING EDGE TURBULENCE PROFILES—N1 NOZZLE
 AR = 8 RECTANGULAR, $h = 1.59$ cm (0.625 in),
 $W = 12.7$ cm (5.0 in), NPR = 1.1

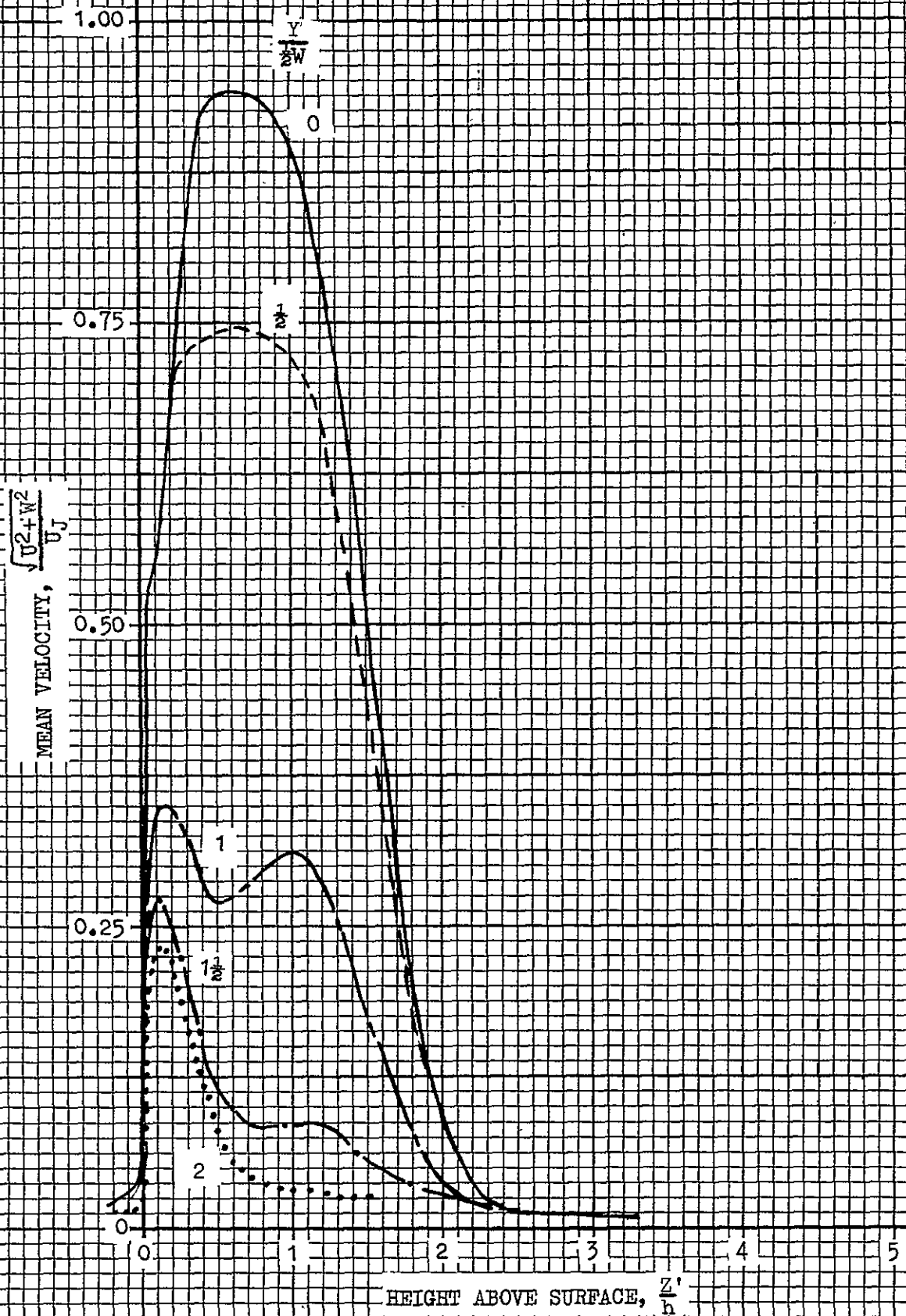


FIGURE 3-43. TRAILING EDGE MEAN VELOCITY PROFILES—N₂ NOZZLE
 AR = 1.27 CIRCULAR, $h = w = 5.08$ cm (2.0 in)', NPR = 1.1

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 KEUFFEL & ESSER CO.

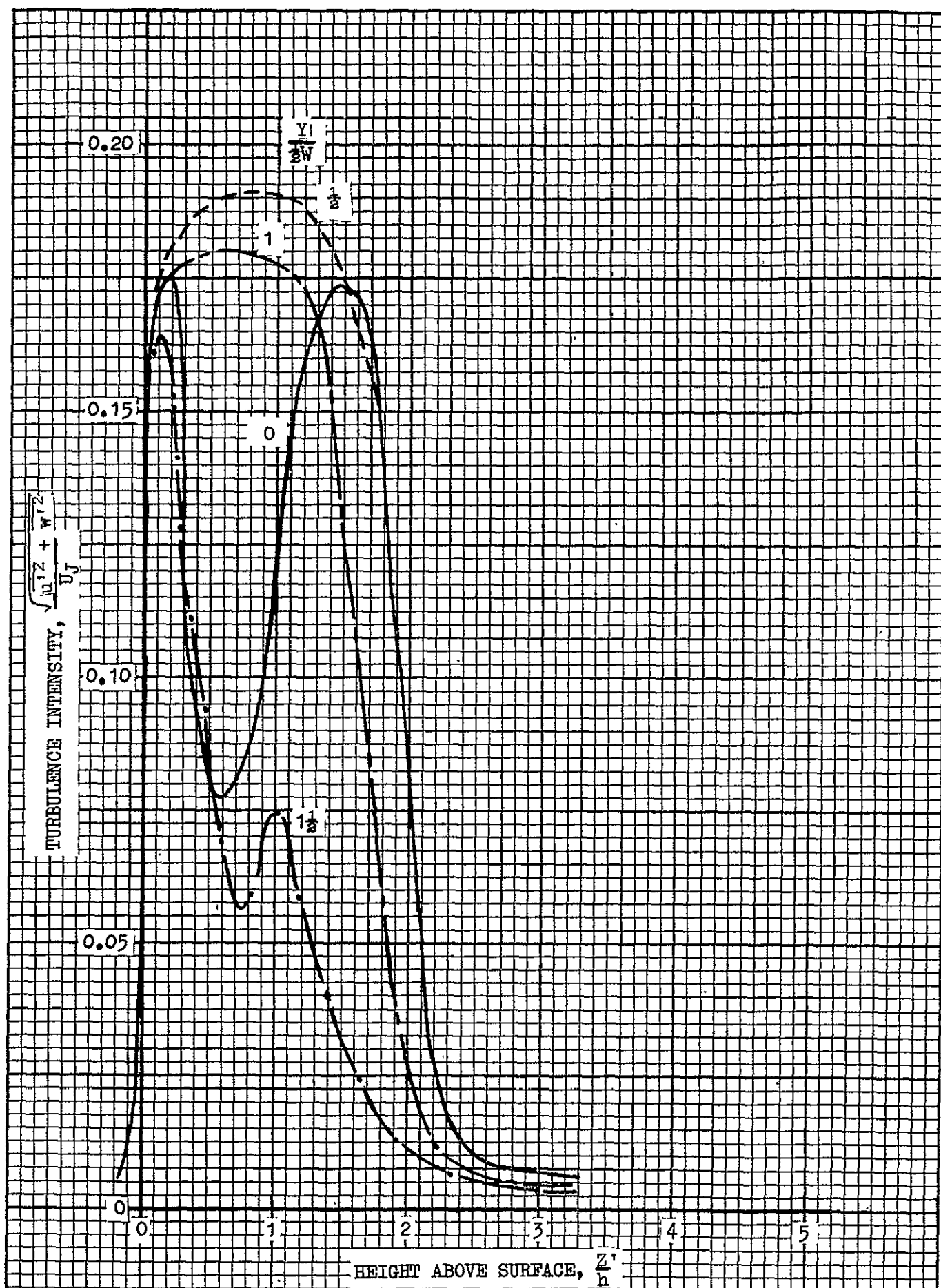


FIGURE 3-44. TRAILING EDGE TURBULENCE PROFILES—N2 NOZZLE
 AR = 1.27 CIRCULAR, $h = w = 5.08$ cm (2.0 in), NPR = 1.1

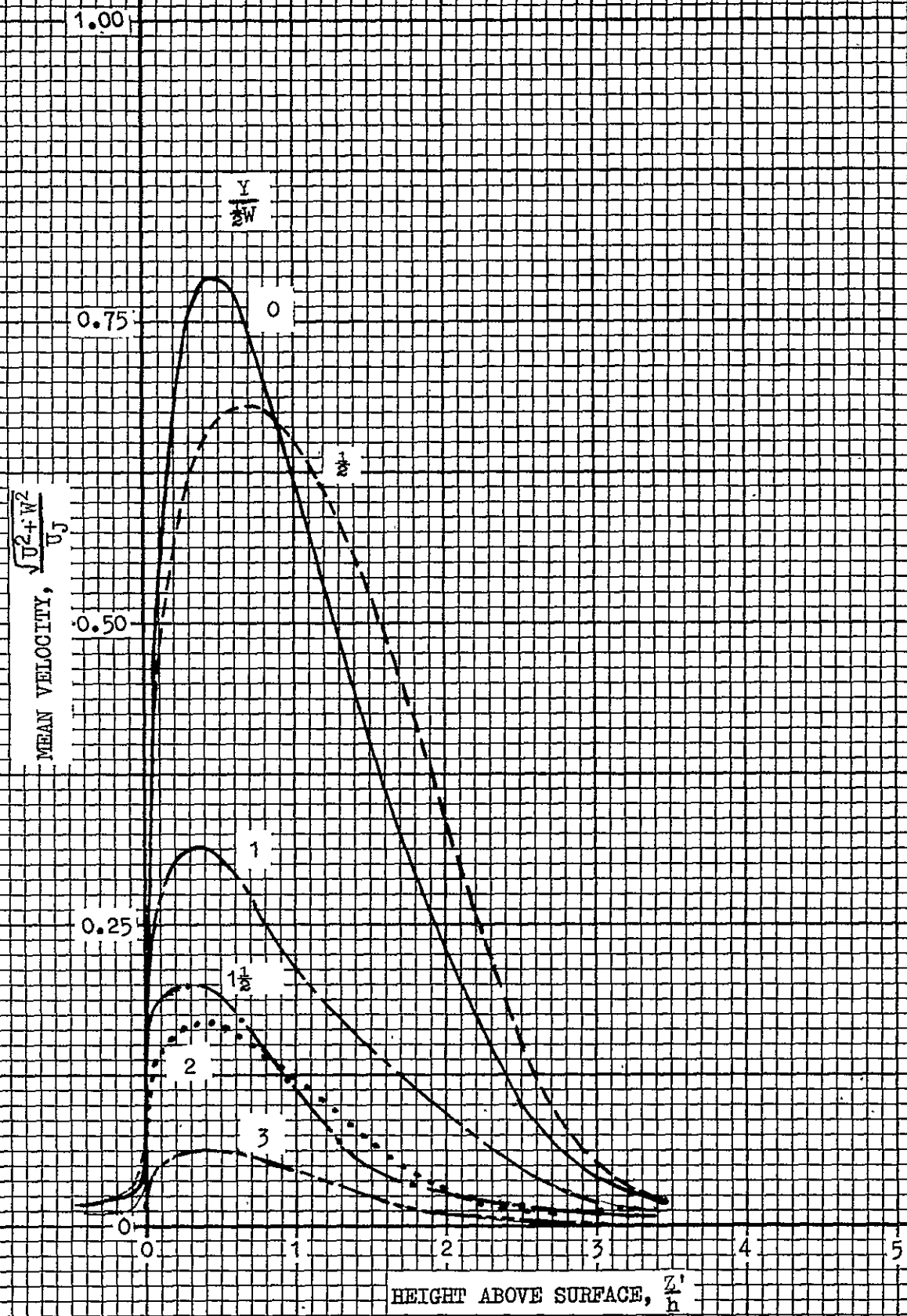


FIGURE 3-45. TRAILING EDGE MEAN VELOCITY PROFILES--N3 NOZZLE
 AR = 4 RECTANGULAR, $h = 2.25$ cm (0.886 in),
 $W = 8.99$ cm 3.54 in), NPR = 1.1

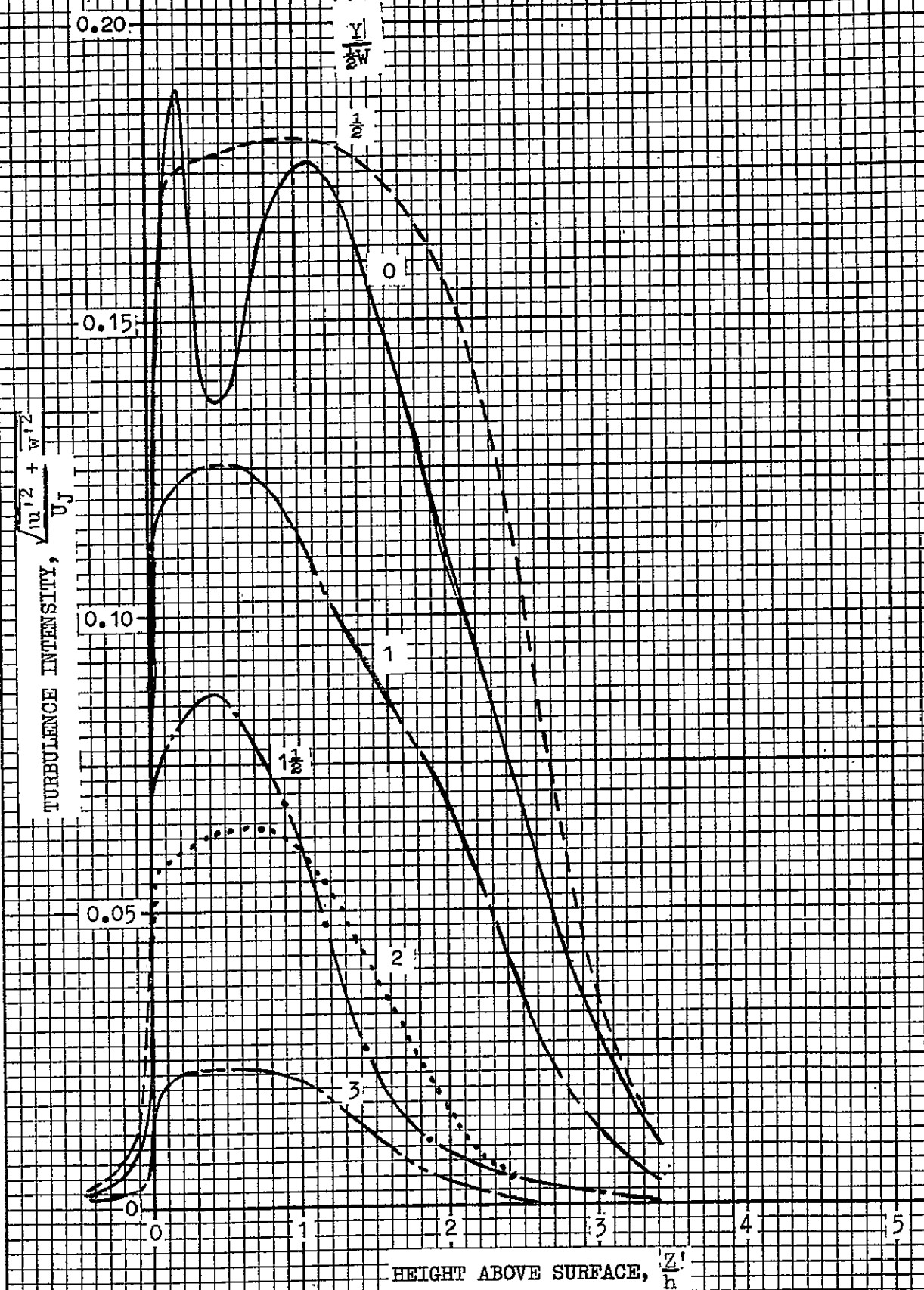


FIGURE 3-46. TRAILING EDGE TURBULENCE PROFILES—N3 NOZZLE
 AR = 4 RECTANGULAR, $h = 2.25$ cm (0.886 in),
 $W = 8.99$ cm 3.54 in), NPR = 1.1

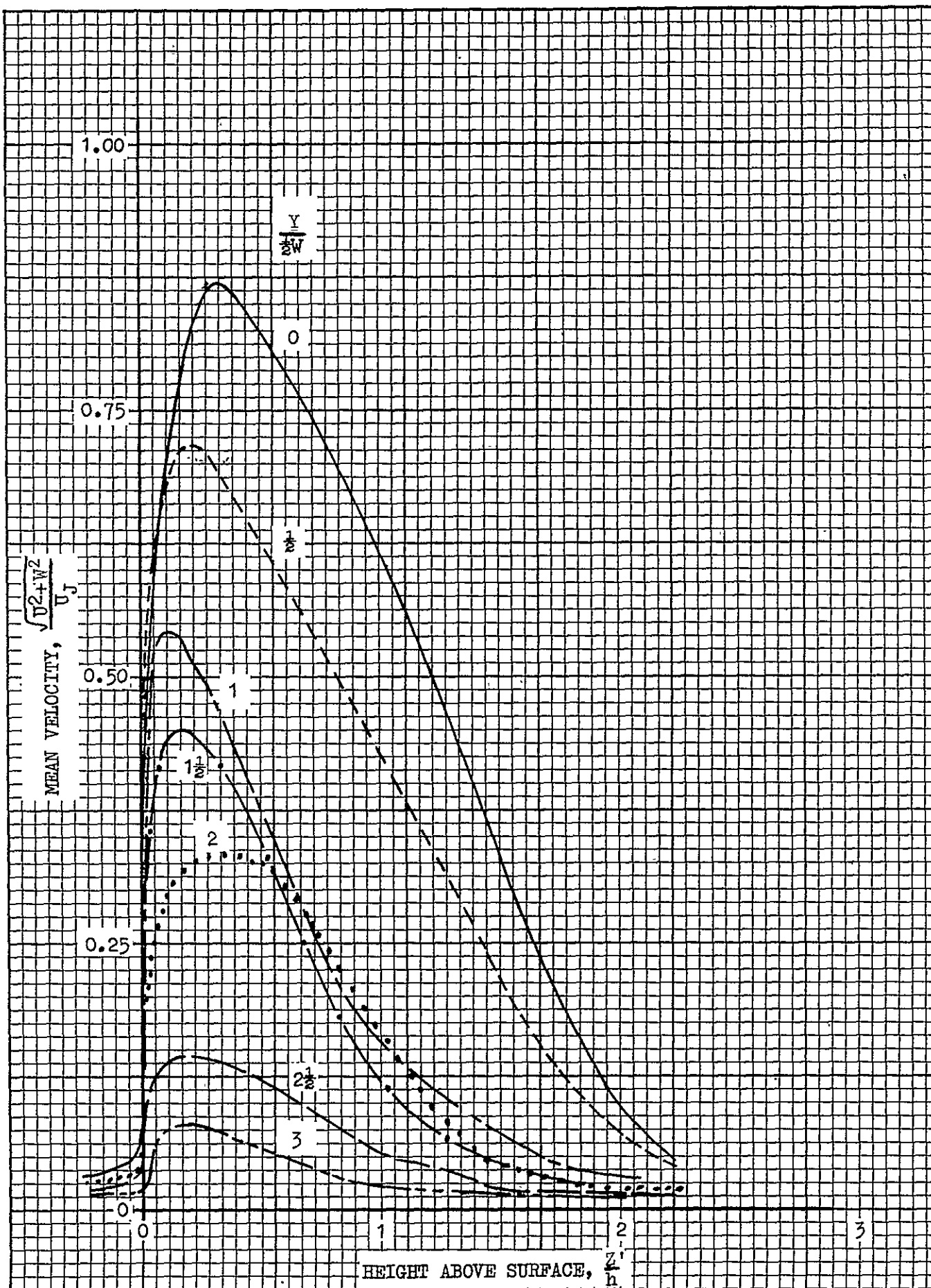


FIGURE 3-47. TRAILING EDGE MEAN VELOCITY PROFILES—N4 NOZZLE
 AR = 2.9 VARIABLE GEOMETRY, $h = 3.5$ cm (1.38 in),
 $W = 7.87$ cm (3.10 in), NPR = 1.1

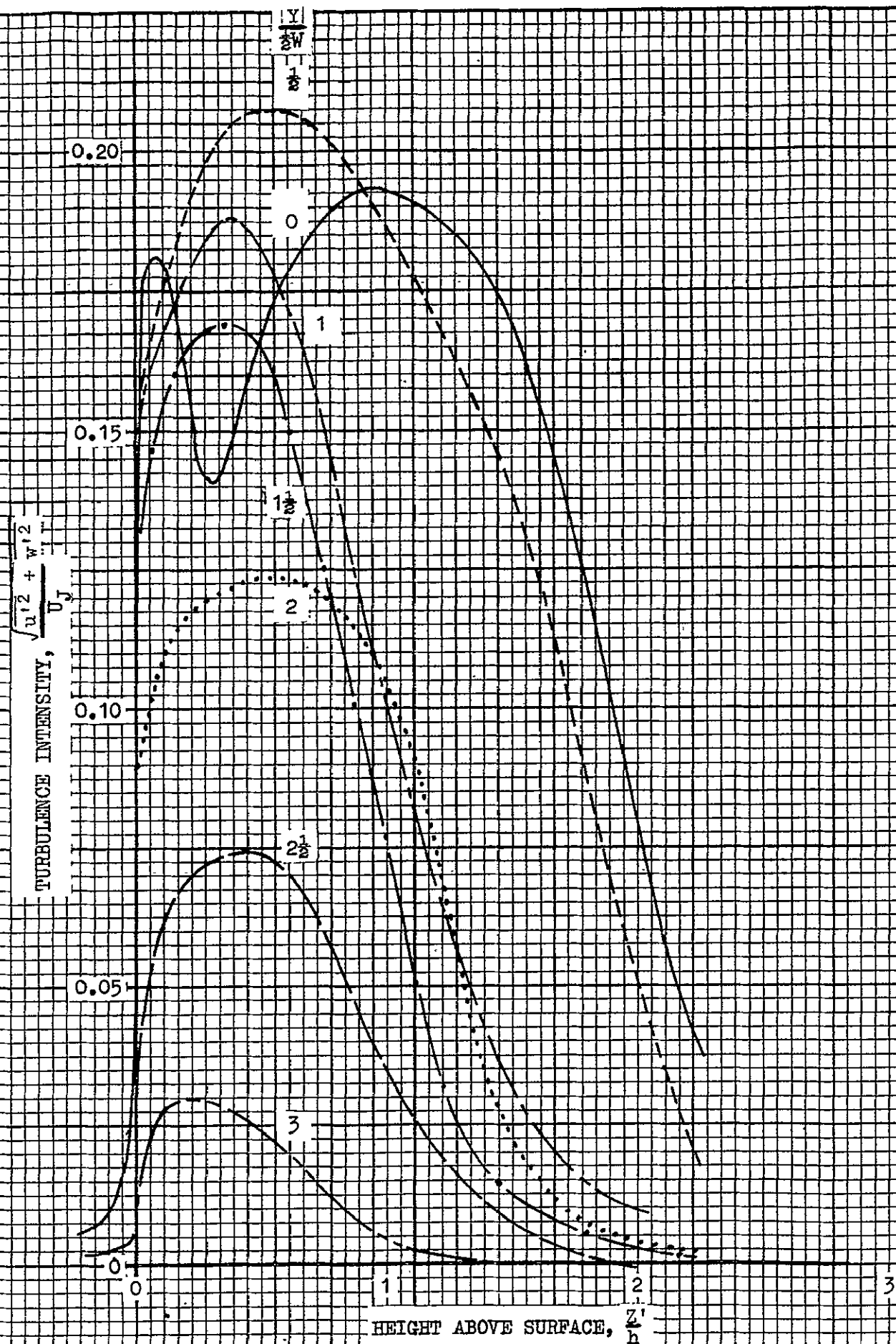


FIGURE 3-48. TRAILING EDGE TURBULENCE PROFILES--N4 NOZZLE
AR = 2.9 VARIABLE GEOMETRY, $h = 3.5$ cm (1.38 in),
 $W = 7.87$ cm (3.10 in) , NPR = 1.1

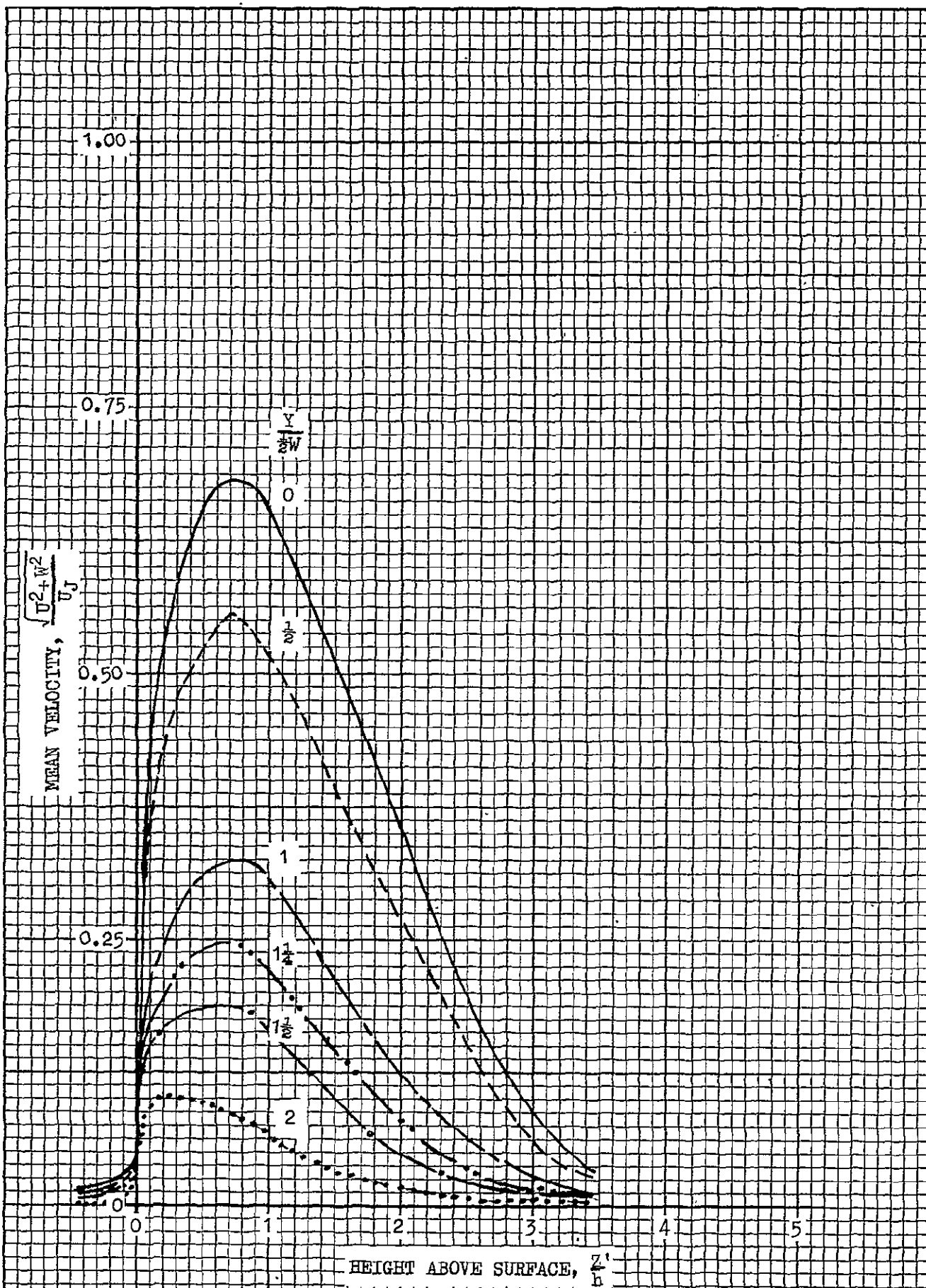


FIGURE 3-49. TRAILING EDGE MEAN VELOCITY PROFILES—N5 NOZZLE
 AR = 3.25 D-SHAPED, $h = 2.25$ cm (0.886 in),
 $W = 5.74$ cm (2.26 in), NPR = 1.1

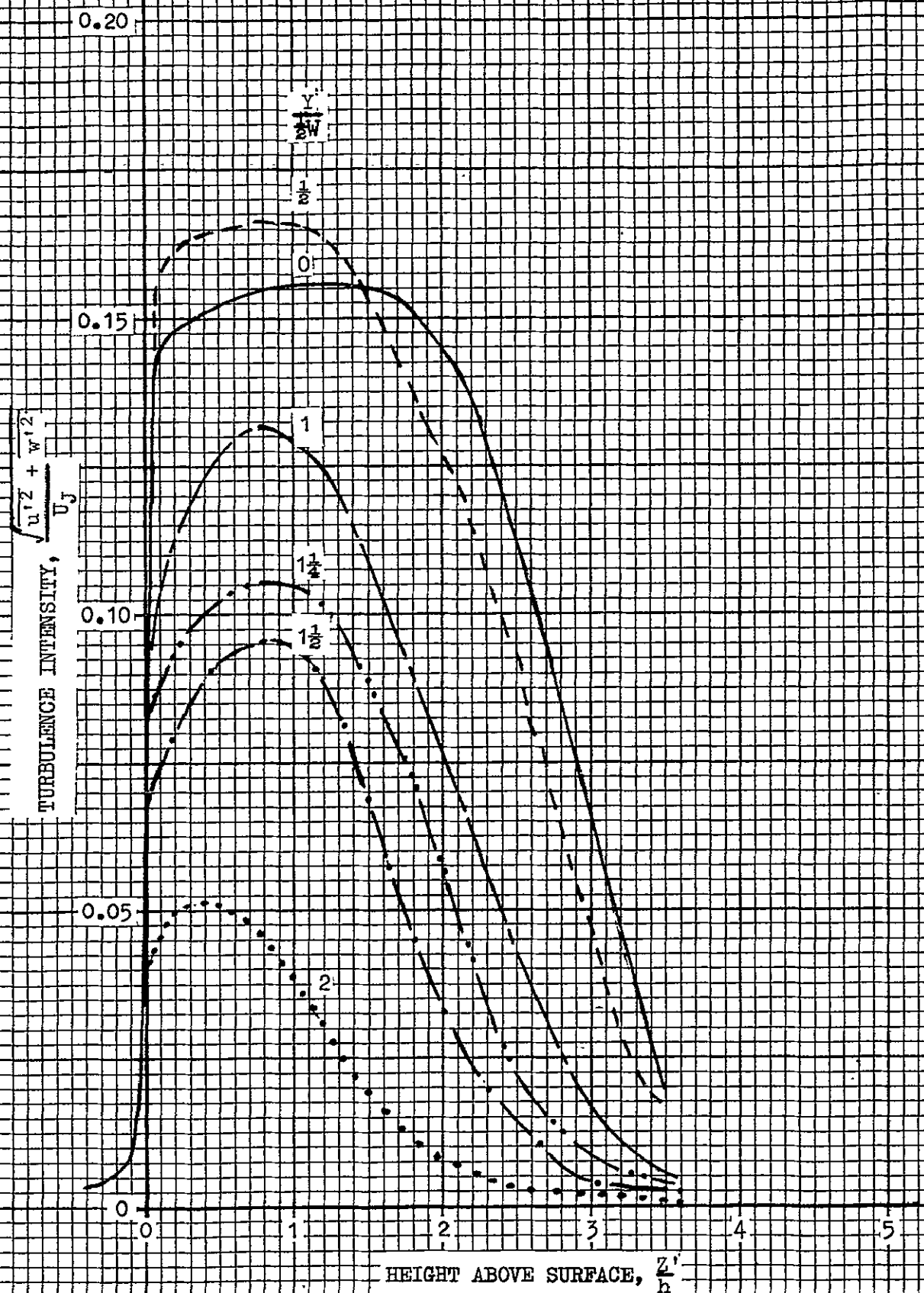


FIGURE 3-50. TRAILING EDGE TURBULENCE PROFILES—N5 NOZZLE

AR = 3.25 D-SHAPED, $h = 2.25$ cm (0.886 in),
 $W = 5.74$ cm (2.26 in), NPR = 1.1

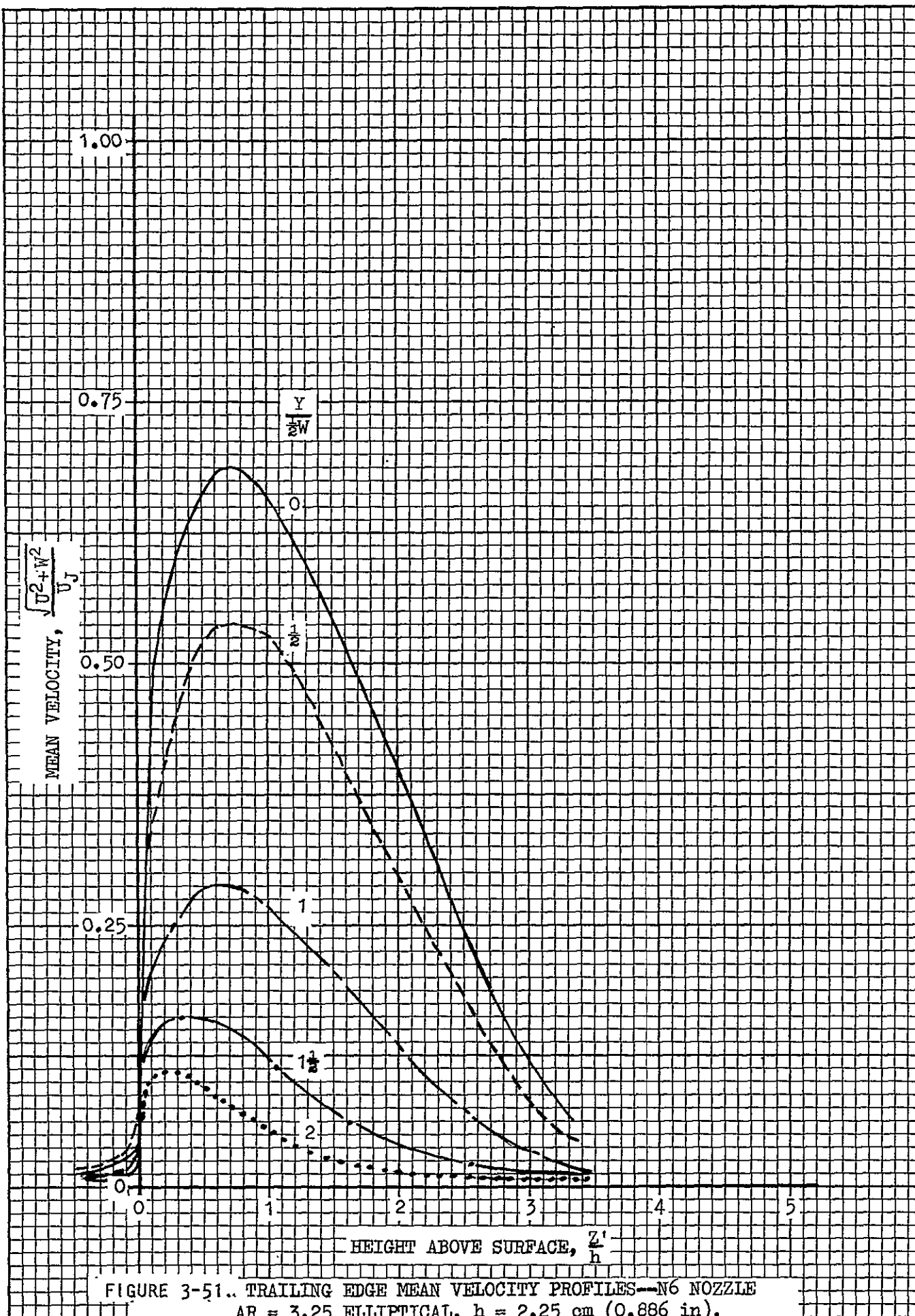


FIGURE 3-51.. TRAILING EDGE MEAN VELOCITY PROFILES--N6 NOZZLE
 AR = 3.25 ELLIPTICAL, $h = 2.25$ cm (0.886 in),
 $W = 5.74$ cm (2.26 in), NPR = 1.1

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OF POOR QUALITY

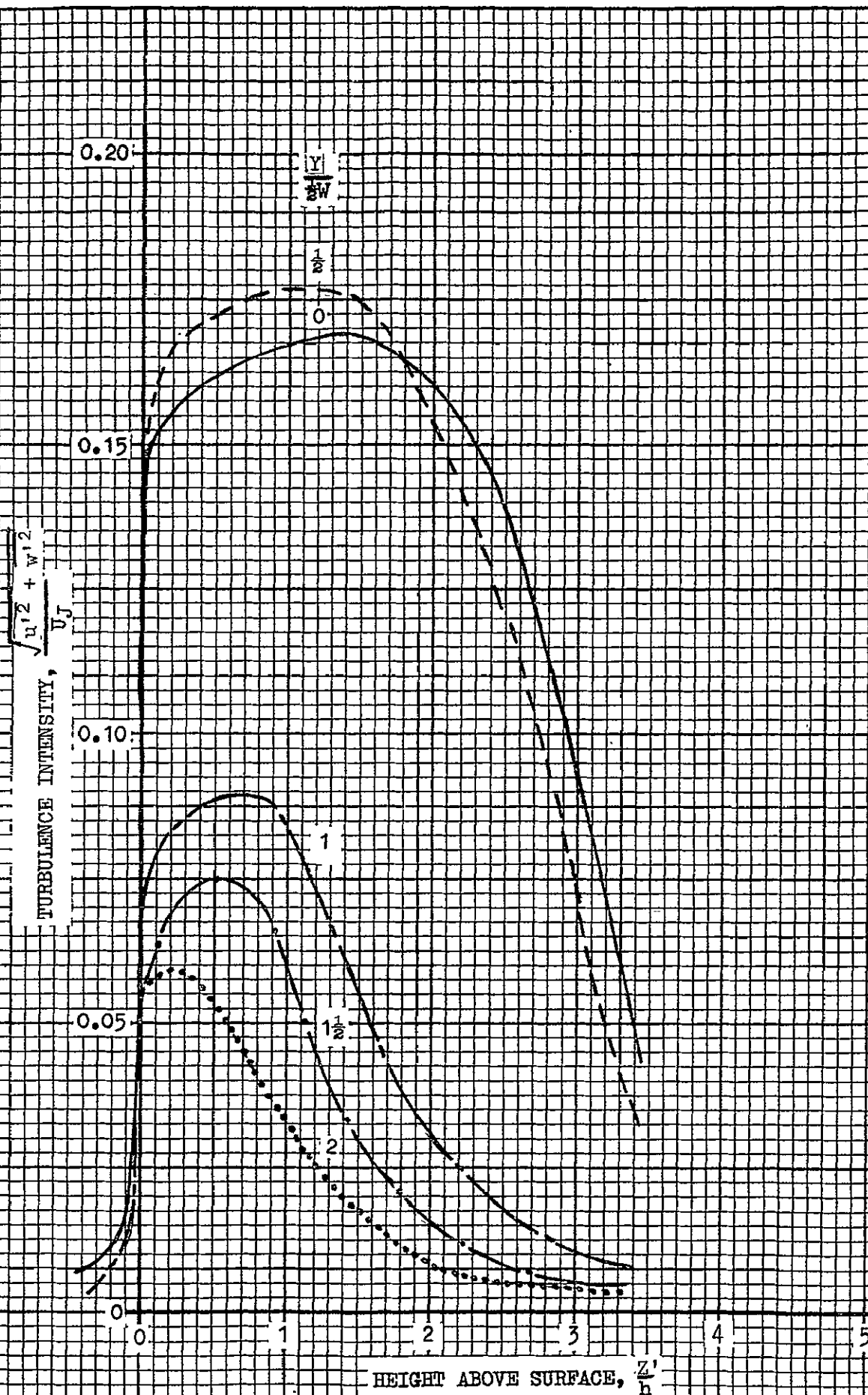


FIGURE 3-52. TRAILING EDGE TURBULENCE PROFILES--N6 NOZZLE

AR = 3.25 ELLIPTICAL, $h = 2.25$ cm (0.886 in),
W = 5.74 cm (2.26 in), NPR = 1.1

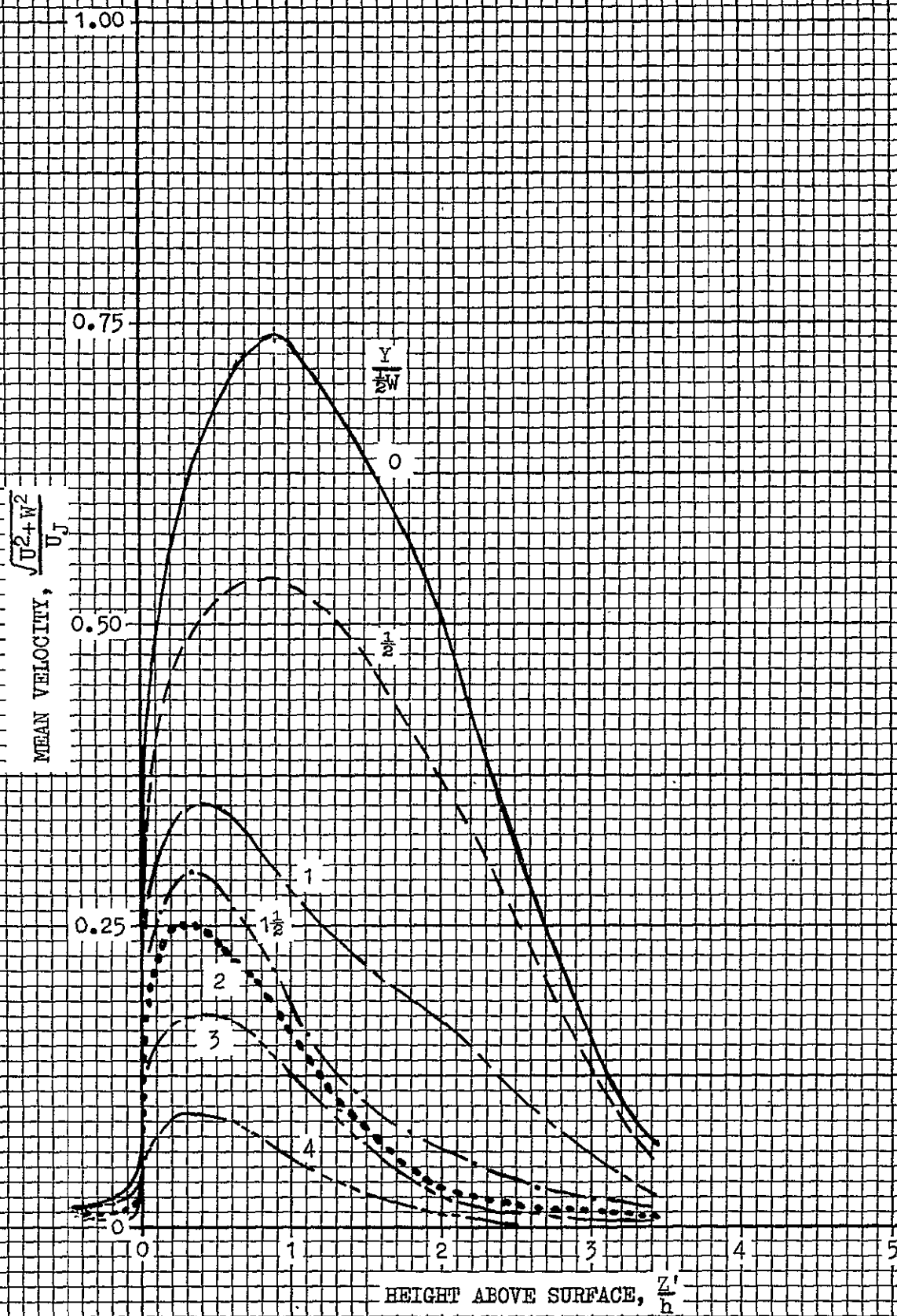


FIGURE 3-53. TRAILING EDGE MEAN VELOCITY PROFILES—N7 NOZZLE
 AR = 2 RECTANGULAR, $h = 2.25$ cm (0.886 in),
 $W = 4.50$ cm (1.77 in), NPR = 1.1

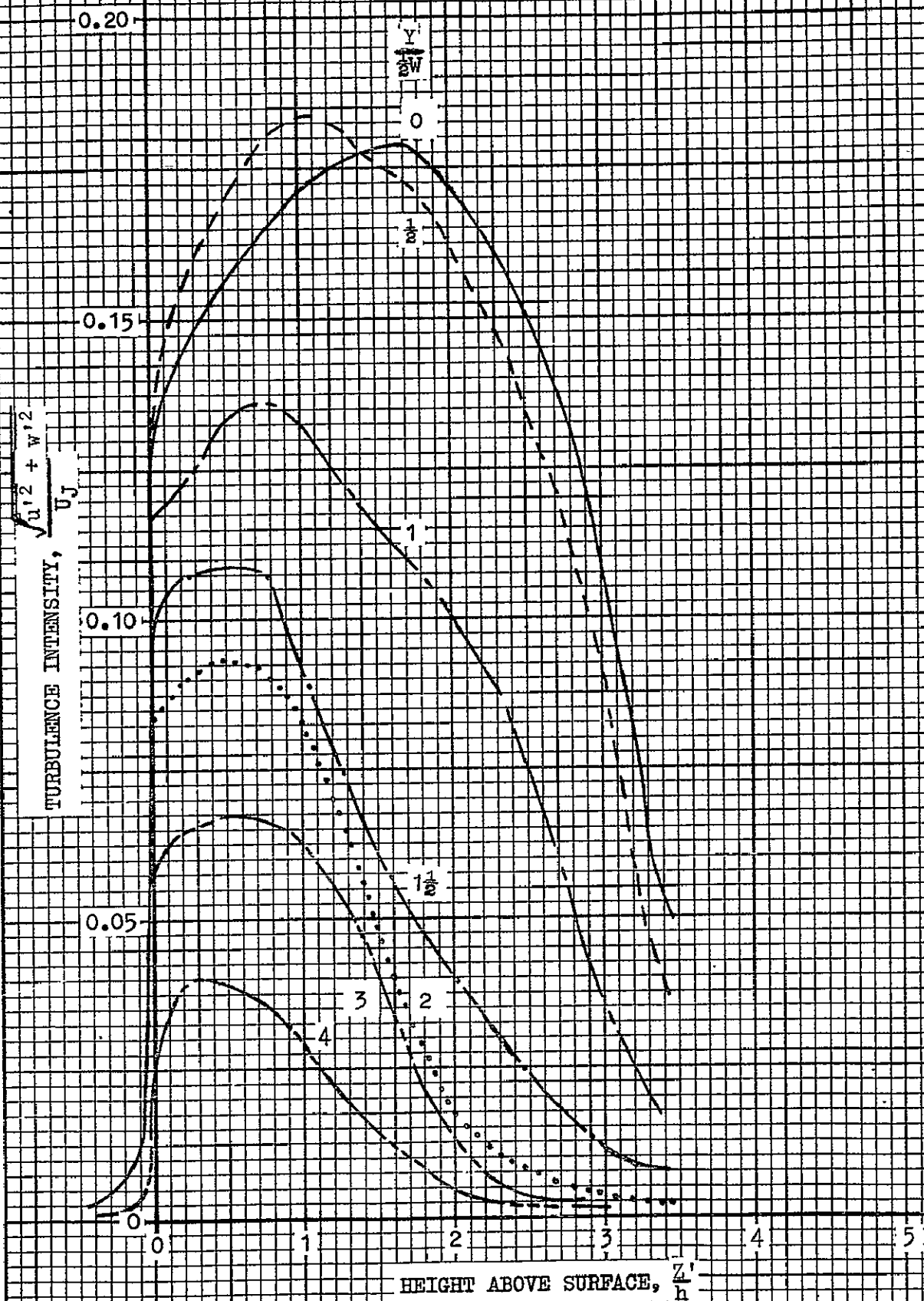


FIGURE 3-54. TRAILING EDGE TURBULENCE PROFILES—N7 NOZZLE
 AR = 2 RECTANGULAR, $h = 2.25$ cm (0.886 in),
 $W = 4.50$ cm (1.77 in), NPR = 1.1

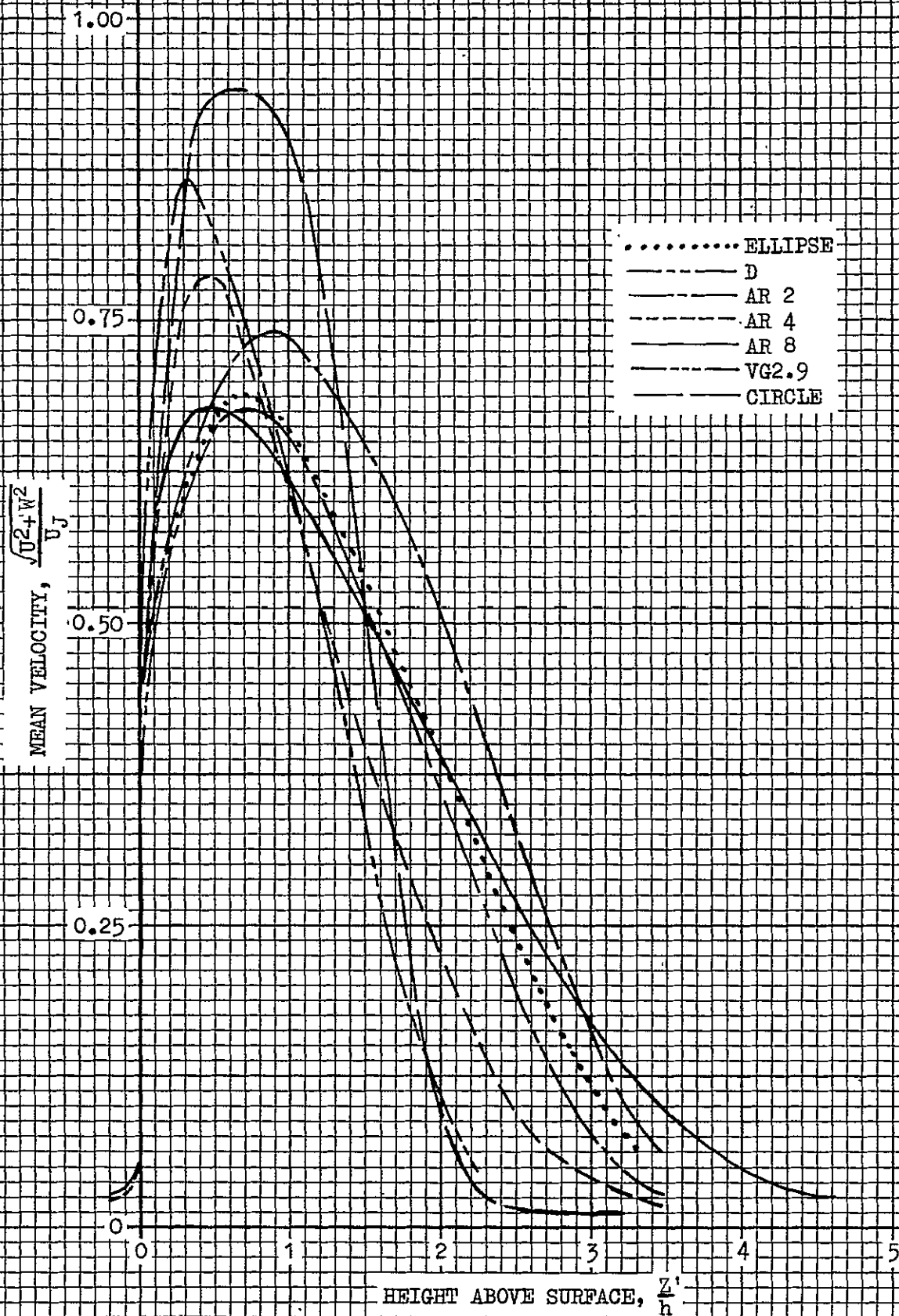


FIGURE 3-55. COMPARISON OF MID-PLANE TRAILING EDGE MEAN VELOCITY PROFILES—N1 THROUGH N7., NPR = 1.1

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 KEUFFEL & ESSER CO.

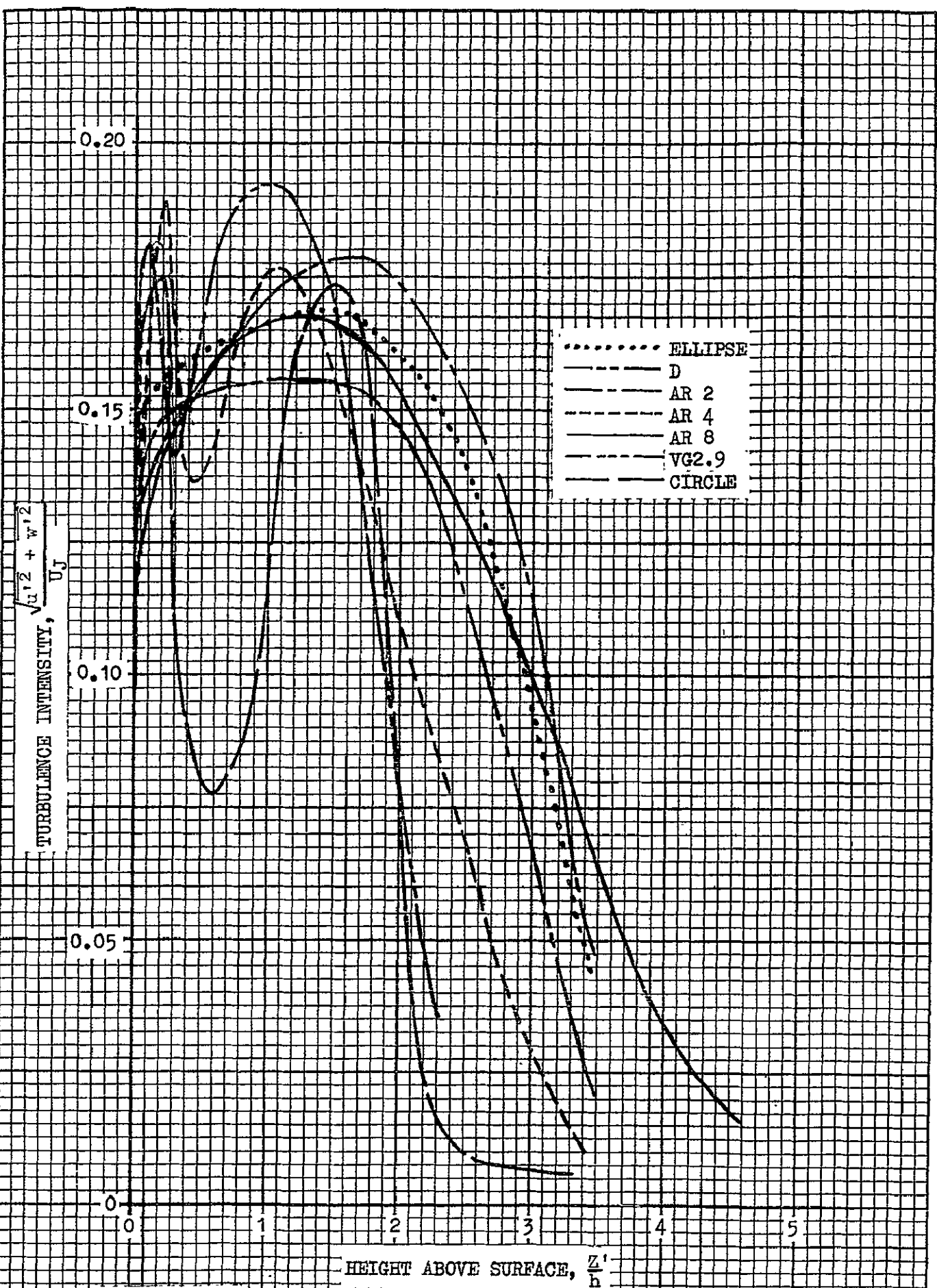


FIGURE 3-56. COMPARISON OF MID-PLANE TRAILING EDGE TURBULENCE
 PROFILES—N1 THROUGH N7., NPR = 1.1

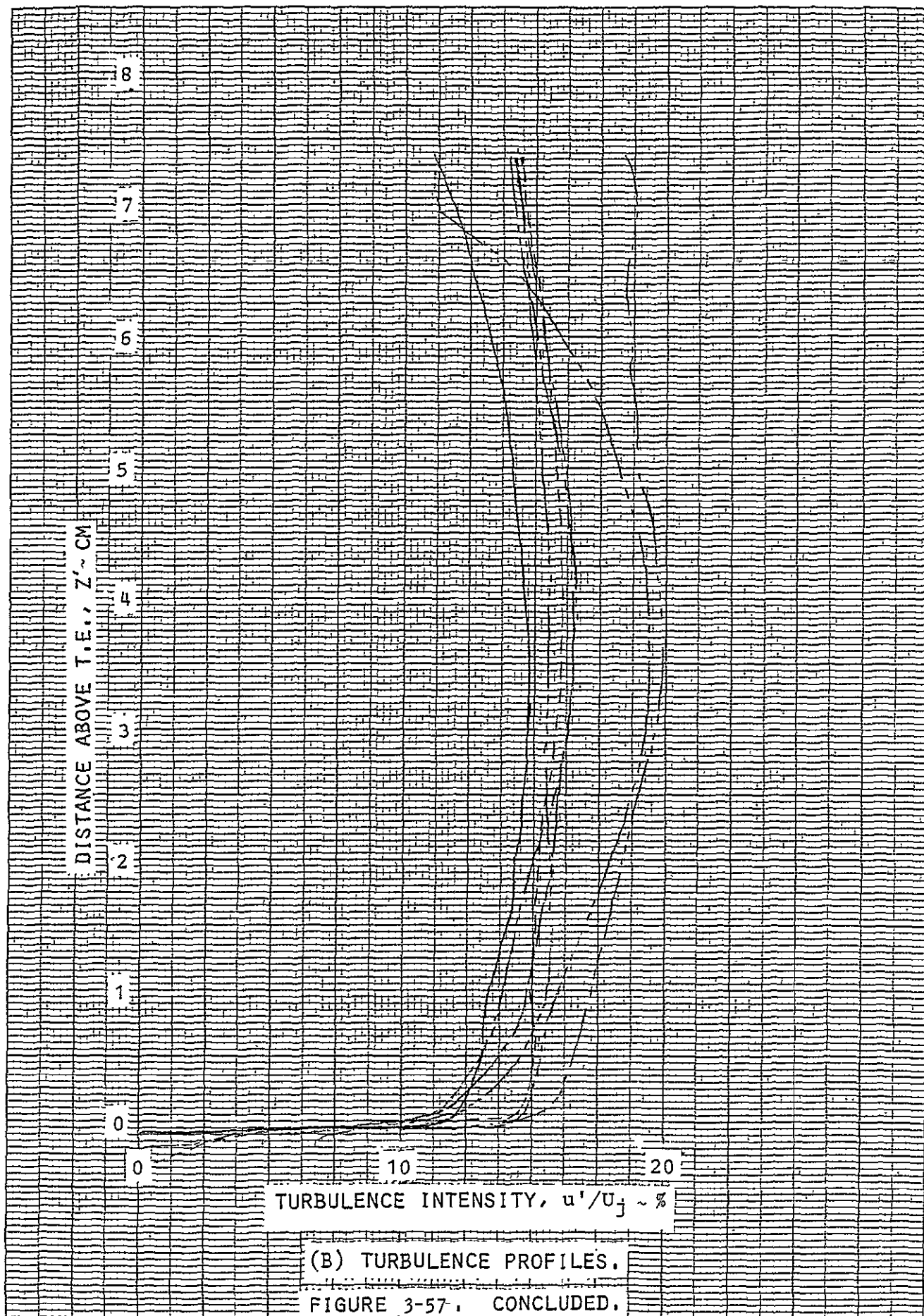
DISTANCE ABOVE T.E., $Z' \sim \text{CM}$

NOZZLE	DIMS., CM	A_N, CM^2
CIRCULAR	5.08	20.27
ELLIPTICAL	5.74 x 2.25	10.13
D	5.74 x 2.25	10.13
AR-2	4.50 x 2.25	10.13
AR-4	9.00 x 2.25	20.27
AR-8	12.73 x 1.59	20.27
QCSEE		29.29

VELOCITY RATIO, $U/U_j \sim \%$

(A) VELOCITY PROFILES.

FIGURE 3-57. EFFECT OF NOZZLE SHAPE ON VELOCITY AND TURBULENCE PROFILES AT TRAILING EDGE. $X_N = .20C$; $\theta_N = 20^\circ$; $NPR = 1.10$; $\delta_f = 60$; $R_c = 7.62 \text{ CM}$; $L_{t.e.} = 6.48 \text{ CM}$.



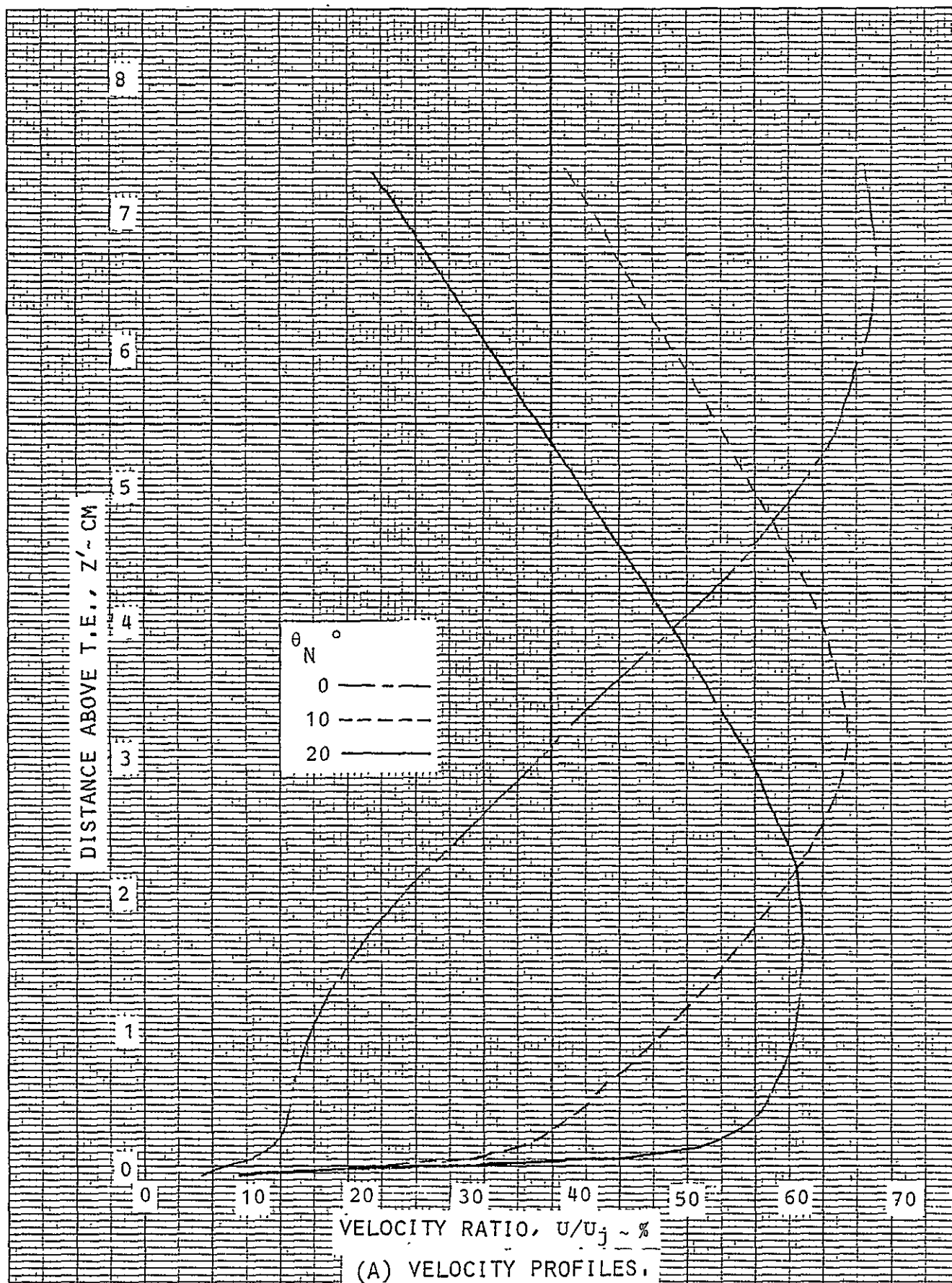


FIGURE 3-58. EFFECT OF IMPINGEMENT ANGLE ON VELOCITY AND TURBULENCE PROFILES AT TRAILING EDGE, AR-8 NOZZLE; $12.73 \text{ CM} \times 1.59 \text{ CM}$; $A_N = 20.27 \text{ CM}^2$; $X_N = .20C$; $\text{NPR} = 1.10$; $\delta_f = 60^\circ$; $R_C = 7.62 \text{ CM}$; $L_{t.e.} = 6.48 \text{ CM}$.

DISTANCE ABOVE T.E., $Z' \sim \text{CM}$

0 1 2 3 4 5 6 7 8

0 10 20

TURBULENCE INTENSITY, $u'/U_j \sim \%$

(B) TURBULENCE PROFILES.
FIGURE 3-58. CONCLUDED.

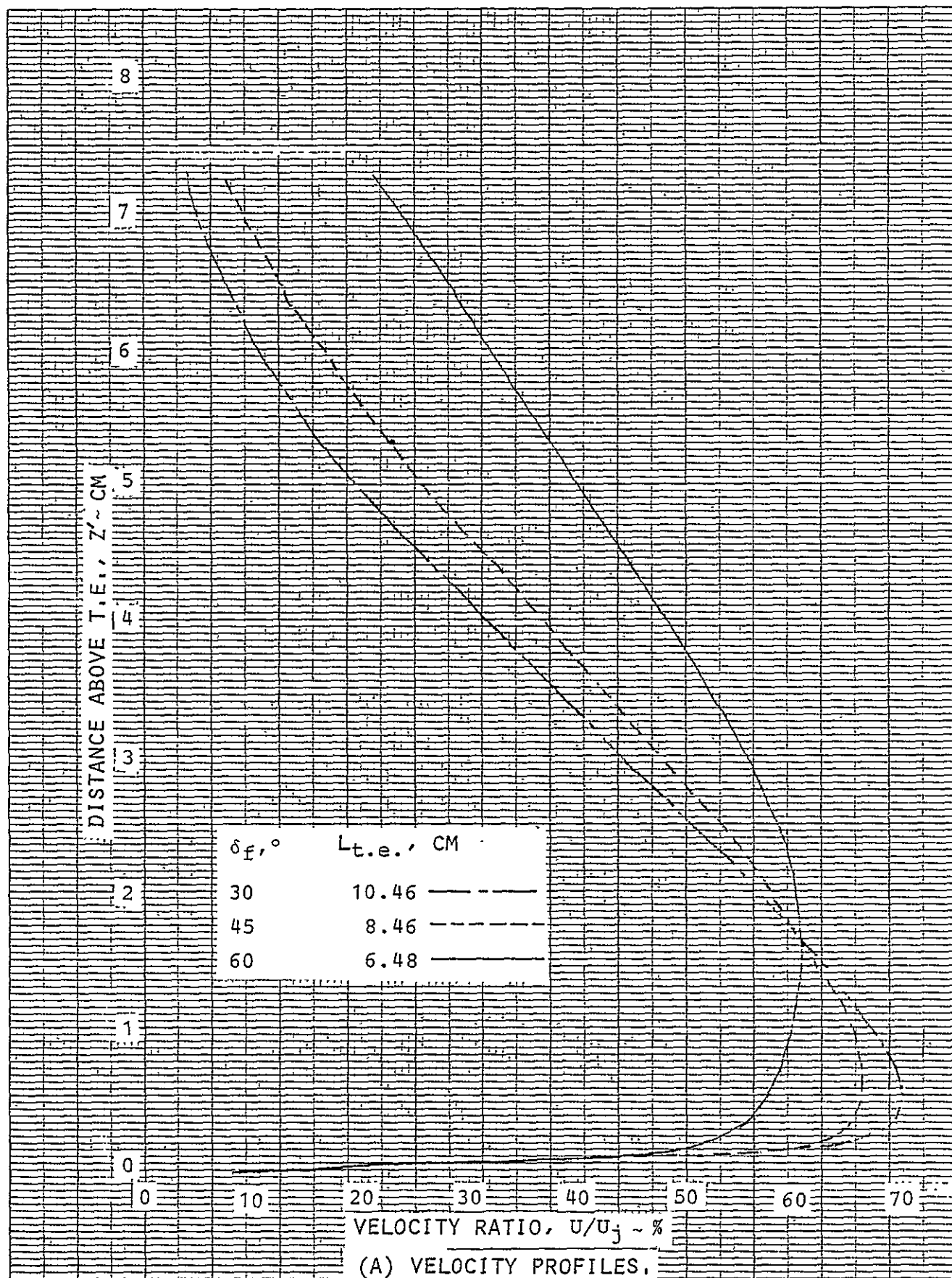
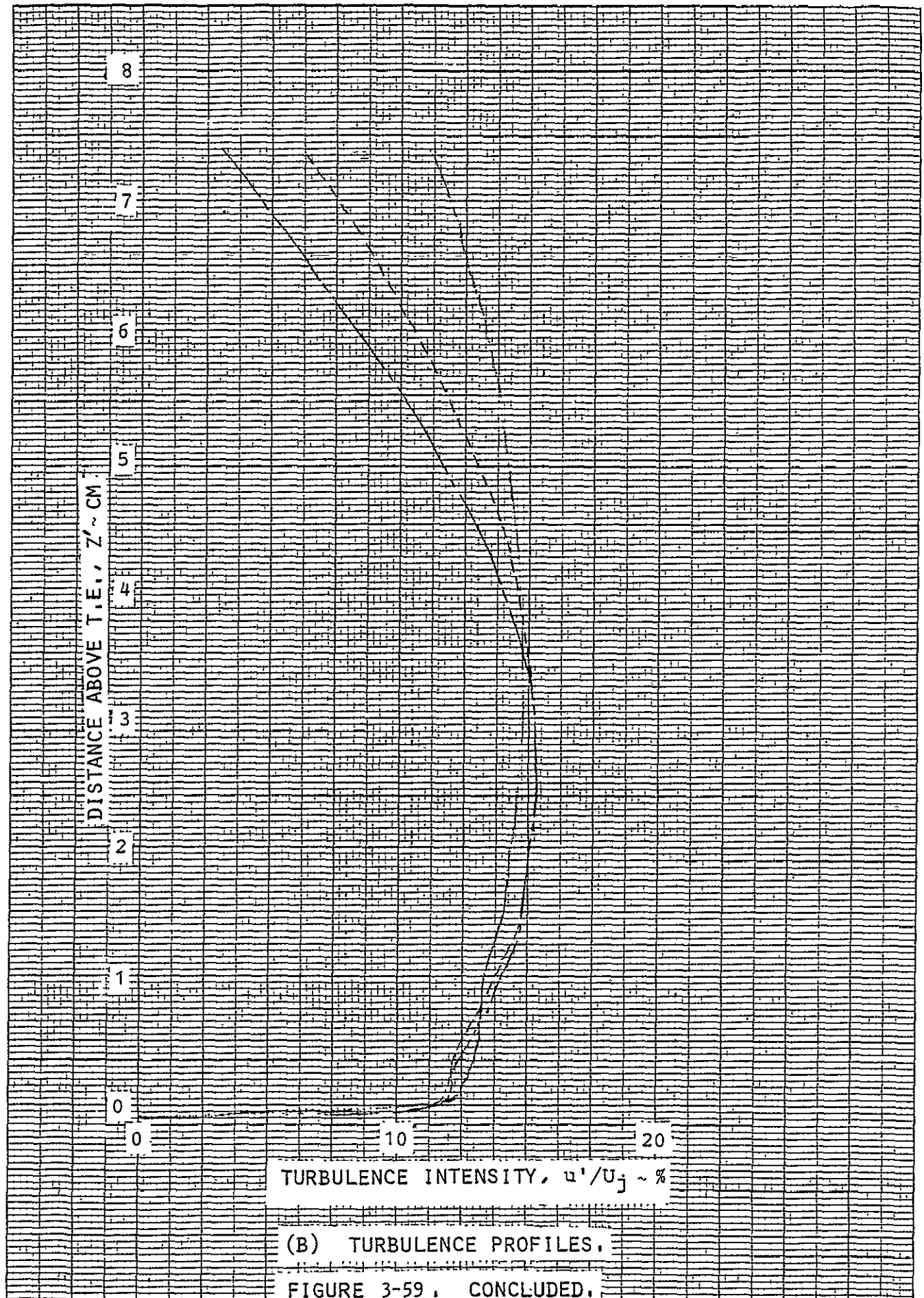


FIGURE 3-59, EFFECT OF FLAP DEFLECTION ON VELOCITY AND TURBULENCE PROFILES AT TRAILING EDGE.
 AR-8 NOZZLE; 12.73 CM x 1.59 CM;
 $A_N = 20.27 \text{ CM}^2$; $X_N = 0.20 \text{ C}$; $\theta_N = 20^\circ$;
 $\text{NPR} = 1.10$; $R_C = 7.62 \text{ CM}$.



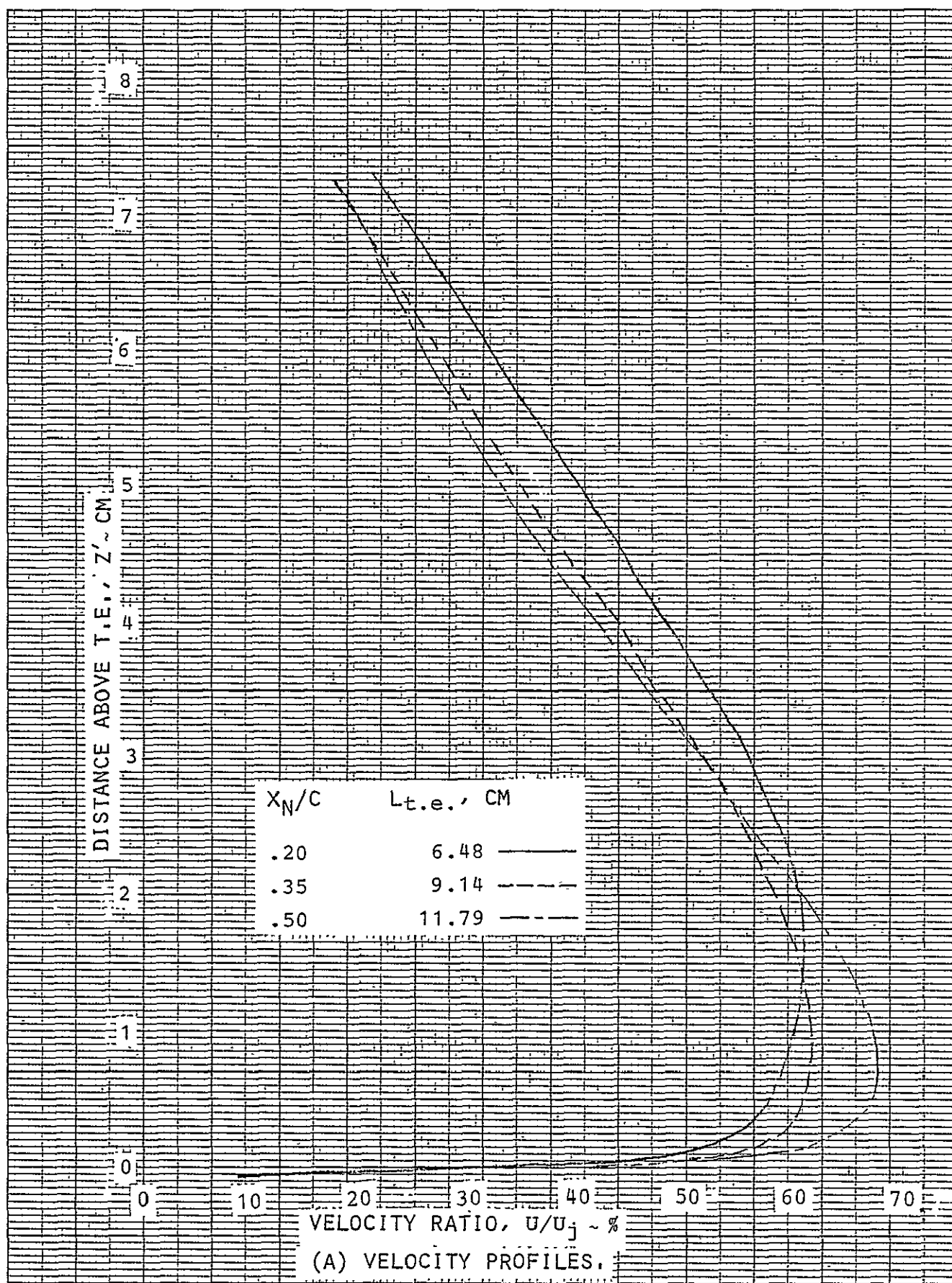


FIGURE 3-60, EFFECT OF CHORDWISE LOCATION OF NOZZLE ON VELOCITY AND TURBULENCE PROFILES AT TRAILING EDGE, AR-8 NOZZLE; 12.73 CM x 1.59 CM; $A_N = 20.27 \text{ CM}^2$; $\theta_N = 20^\circ$; $\text{NPR} = 1.10$; $\delta_F = 60^\circ$; $R_C = 7.62 \text{ CM}$,

DISTANCE ABOVE T.E., $Z' \sim \text{CM}$

8
7
6
5
4
3
2
1
0

TURBULENCE INTENSITY, $u'/U_j \sim \%$

20

(B) TURBULENCE PROFILES,

FIGURE 3-60, CONCLUDED.

DISTANCE ABOVE T.E., Z' , CM $L_{t.e.}$, CM

3.81

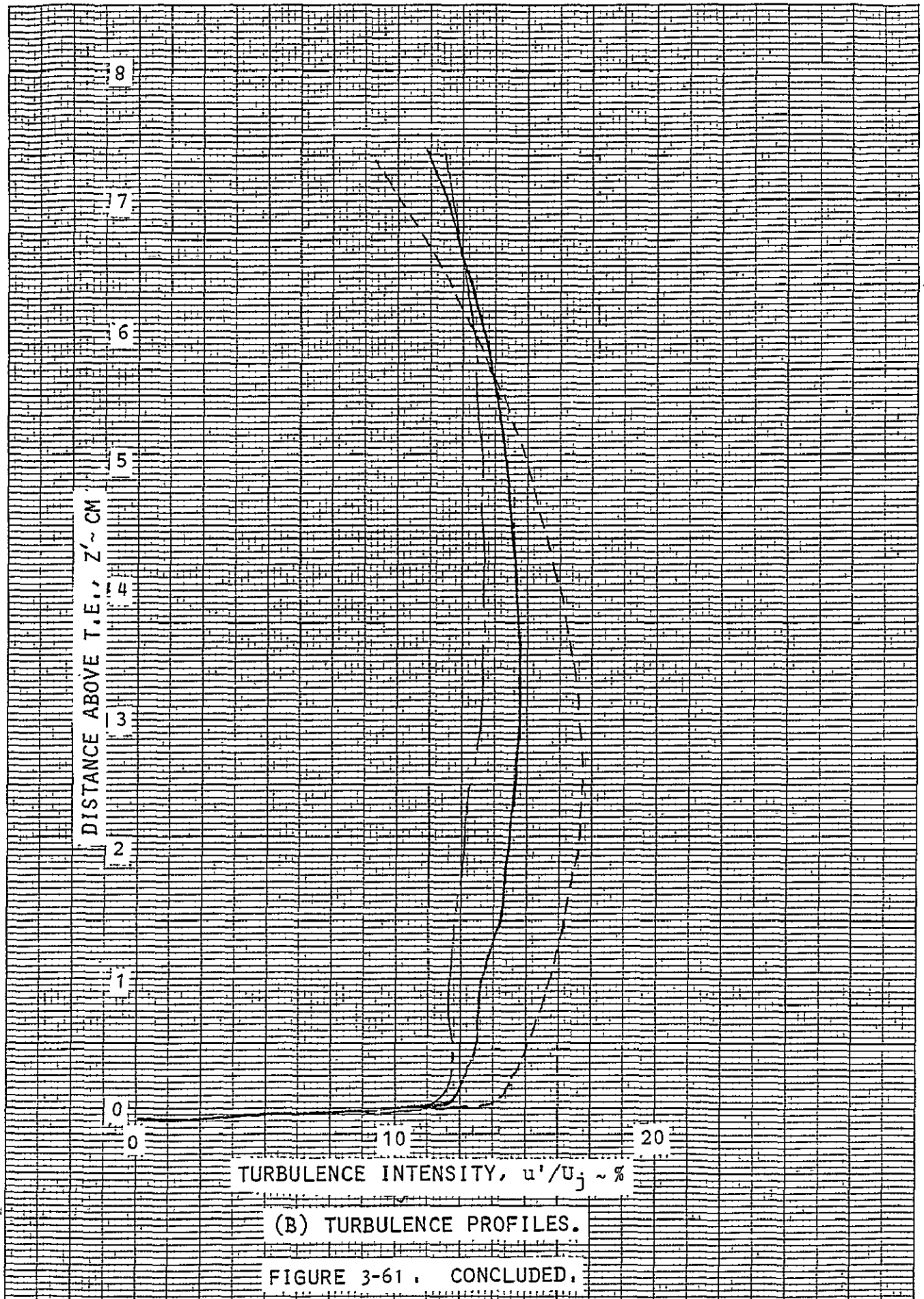
6.48

9.14

VELOCITY RATIO, U/U_j , %

(A) VELOCITY PROFILES.

FIGURE 3-61, EFFECT OF TRAILING EDGE LENGTH ON VELOCITY AND TURBULENCE PROFILES AT TRAILING EDGE, AR-8 NOZZLE; 12.73 CM x 1.59 CM; $A_N = 20.27$ CM; $X_N = .20$; $\theta_N = 20^\circ$; $NPR = 1.10$; $\epsilon = 60^\circ$; $R_C = 7.62$ CM.



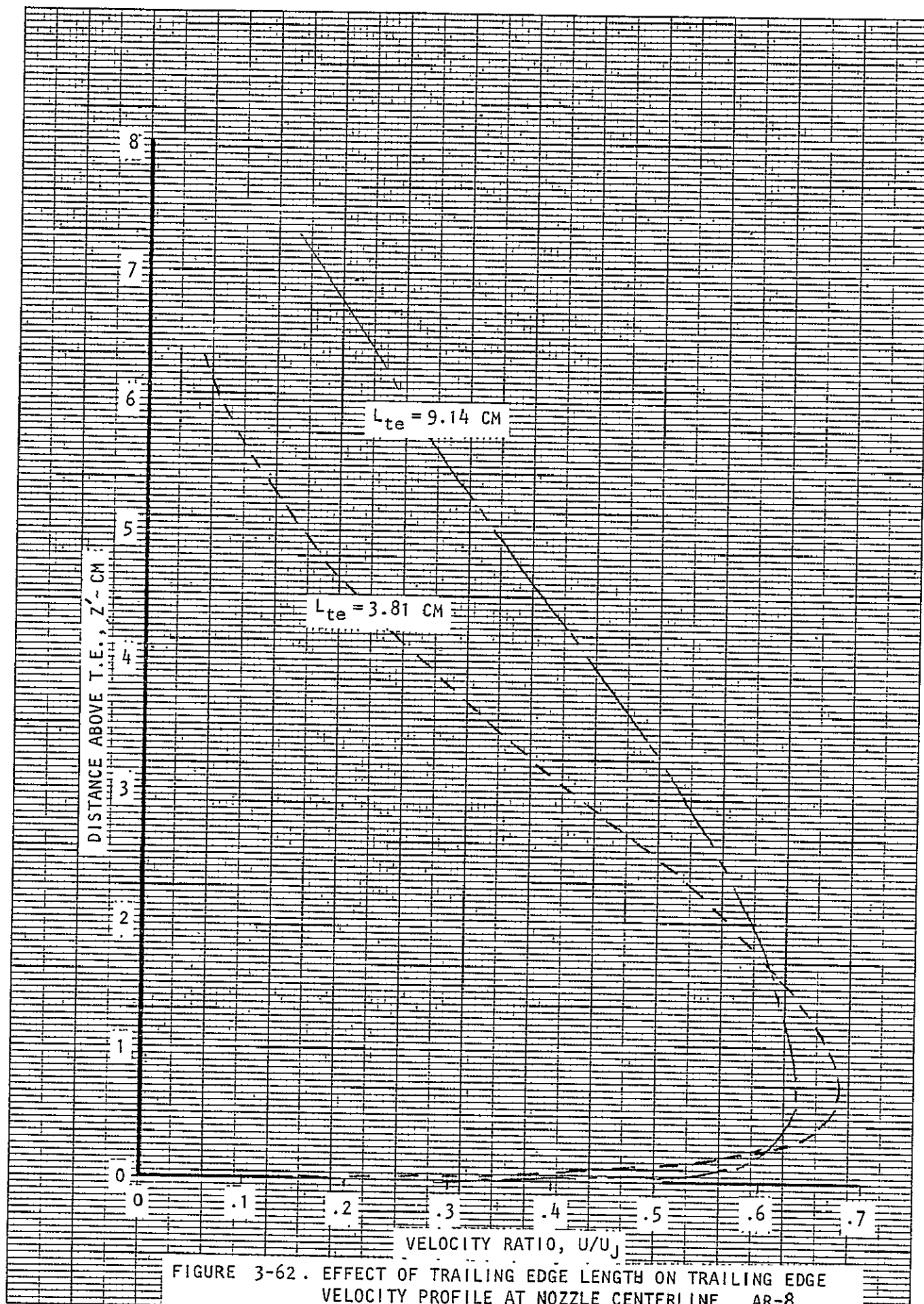


FIGURE 3-62. EFFECT OF TRAILING EDGE LENGTH ON TRAILING EDGE VELOCITY PROFILE AT NOZZLE CENTERLINE. AR-8 NOZZLE; $X_N = .20C$; $\theta_N = 20^\circ$; $R_C = 5.08 \text{ CM}$; $\delta_F = 60^\circ$; $NPR = 1.1$.

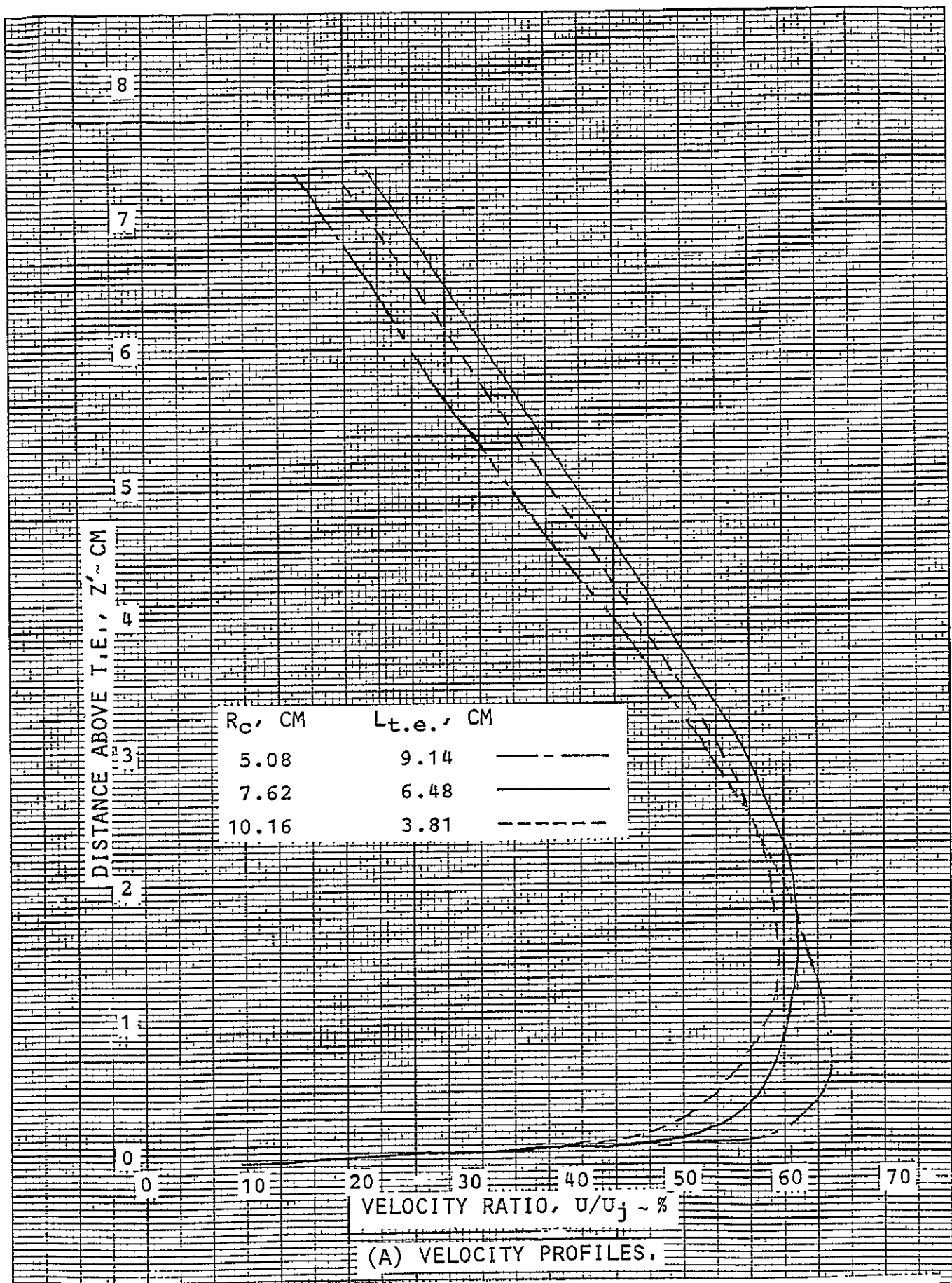
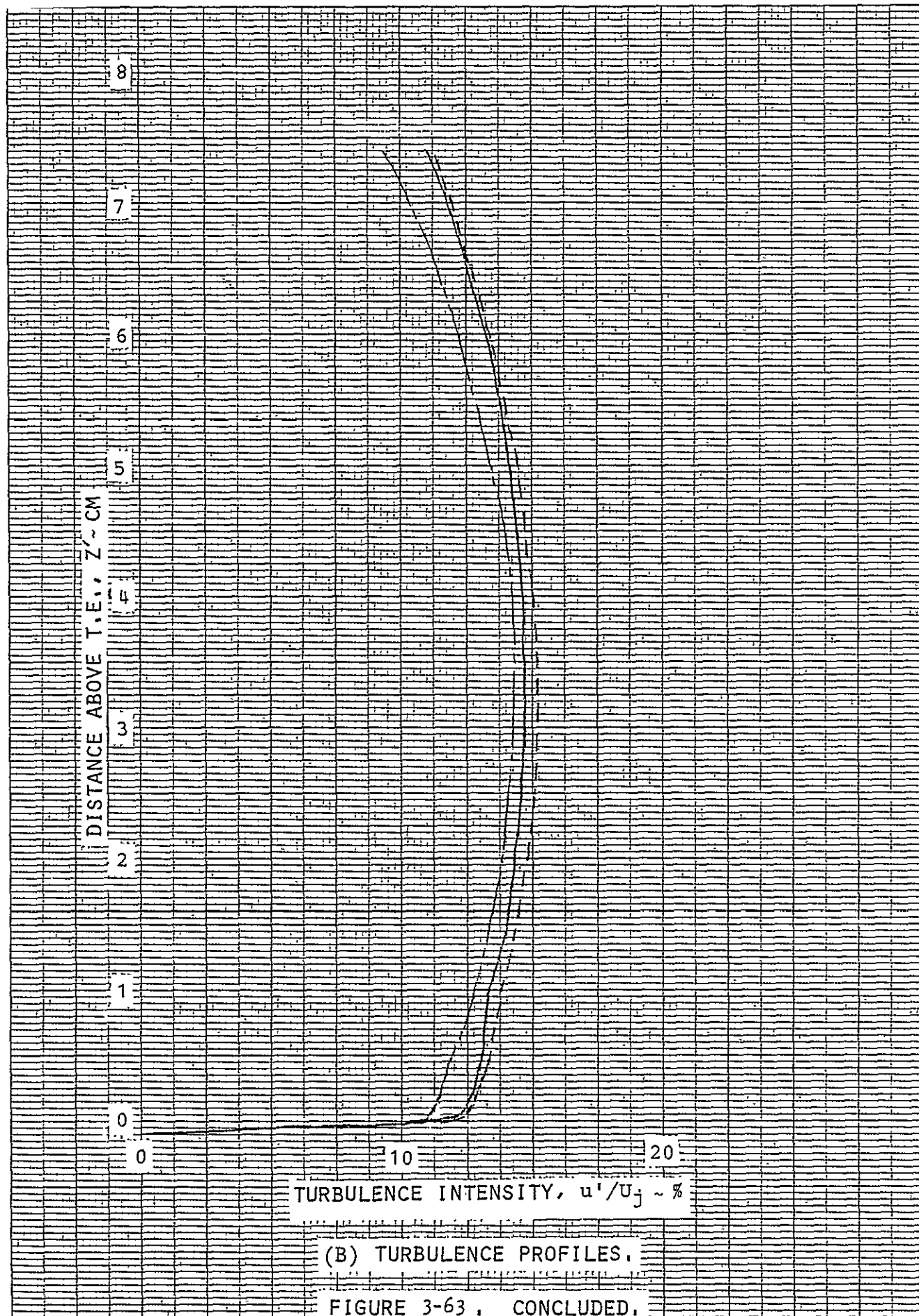
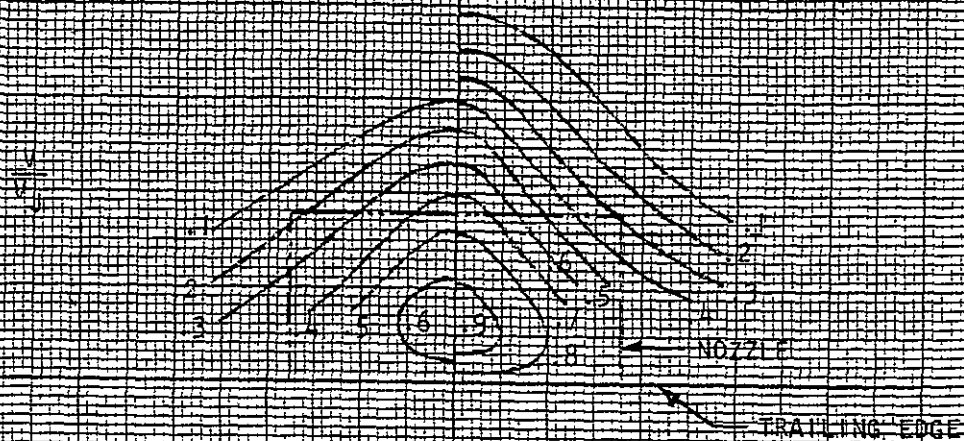


FIGURE 3-63. EFFECT OF FLAP RADIUS ON VELOCITY AND TURBULENCE PROFILES AT TRAILING EDGE. AR-8 NOZZLE; 12.73 CM $\times$ 1.59 CM; $A_N = 20.27$ CM²; $X_N = .20$; $\theta_N = 20^\circ$; NPR = 1.10; $\delta_f = 60^\circ$.

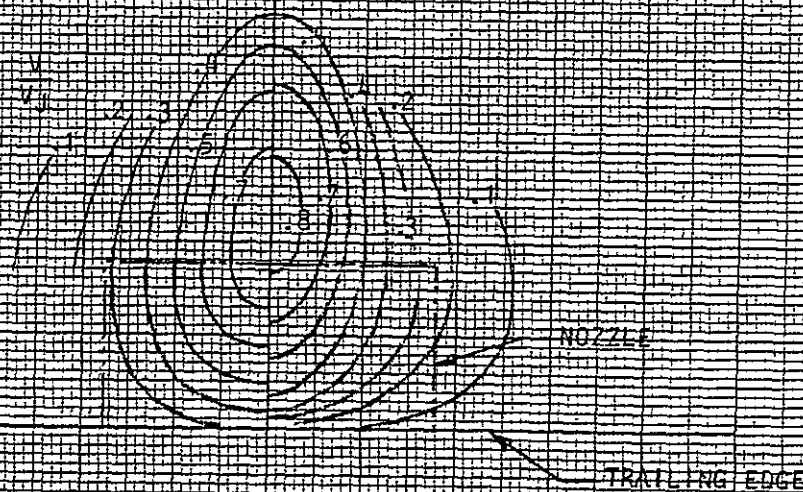




(A) $\alpha = 10^\circ$; $R_n = 5.08 \text{ CM}$; $L_{T-E} = 6.48 \text{ CM}$; $V_0 = 0$.

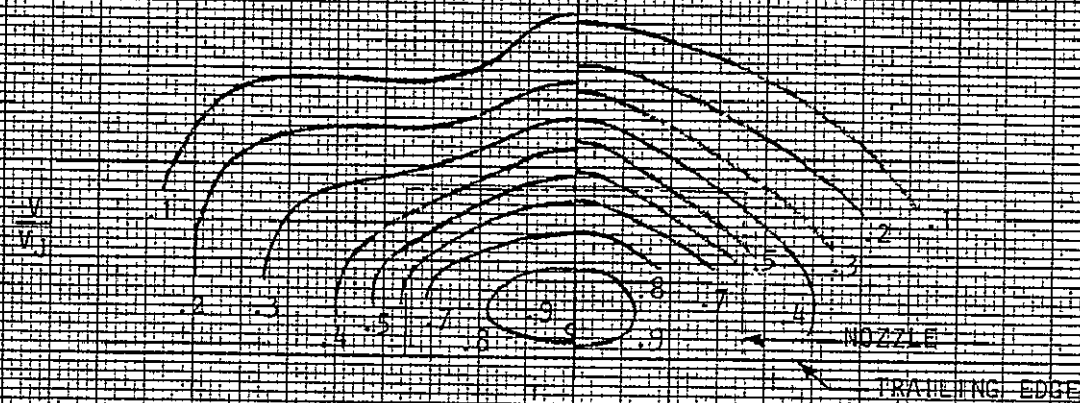
$V_j = 215 \text{ M/S}$

$V_j = 235 \text{ M/S}$



(B) $\alpha = 60^\circ$; $R_n = 10.16 \text{ CM}$; $L_{T-E} = 3.81 \text{ CM}$; $V_0 = 0$.

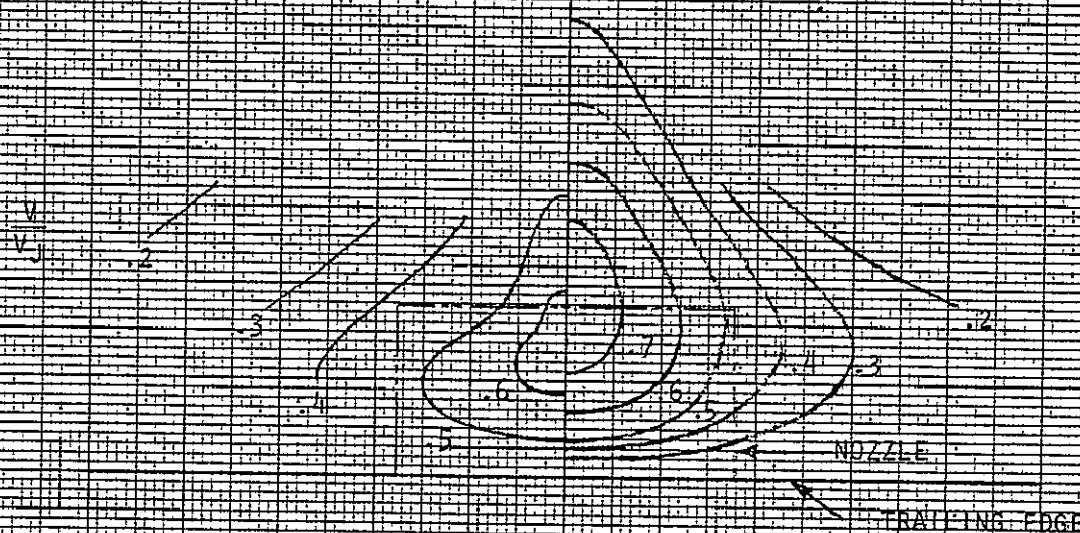
FIGURE 3-64. VELOCITY RATIO CONTOURS AT TRAILING EDGE
NOZZLE = AR=2; $A_N = 10.13 \text{ CM}^2$; $\theta_N = 20^\circ$;
 $X_N = .206$.



(C) $\delta_F = 30^\circ$; $R_C = 5.08$ CM; $L_{T.E.} = 6.48$ CM; $V_0 = 31$ M/S

$V_J = 275$ M/S

$V_J = 285$ M/S



(D) $\delta_F = 60^\circ$; $R_C = 10.16$ CM; $L_{T.E.} = 3.81$ CM; $V_0 = 31$ M/S

FIGURE 3-64. CONTINUED.

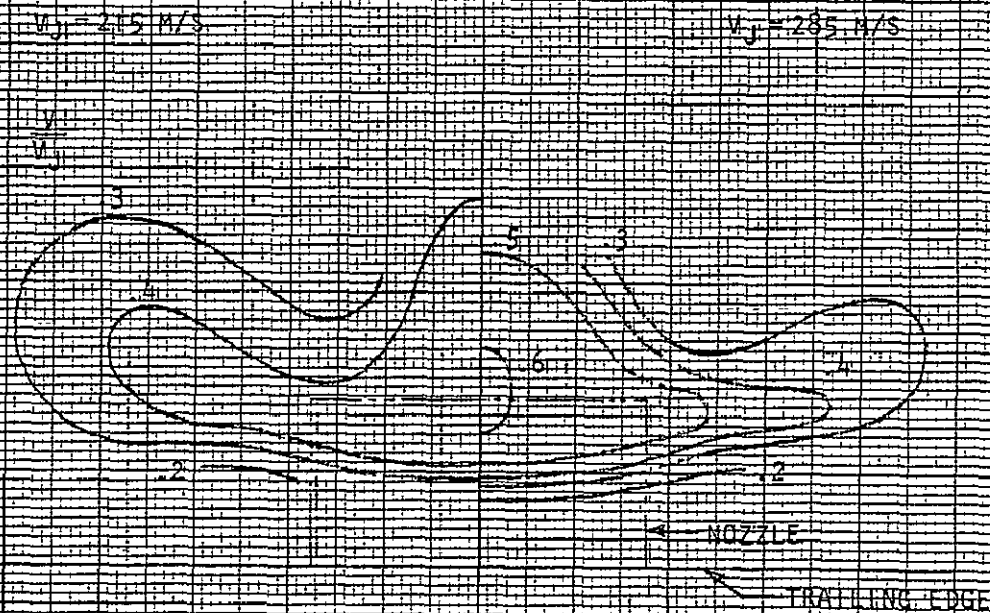
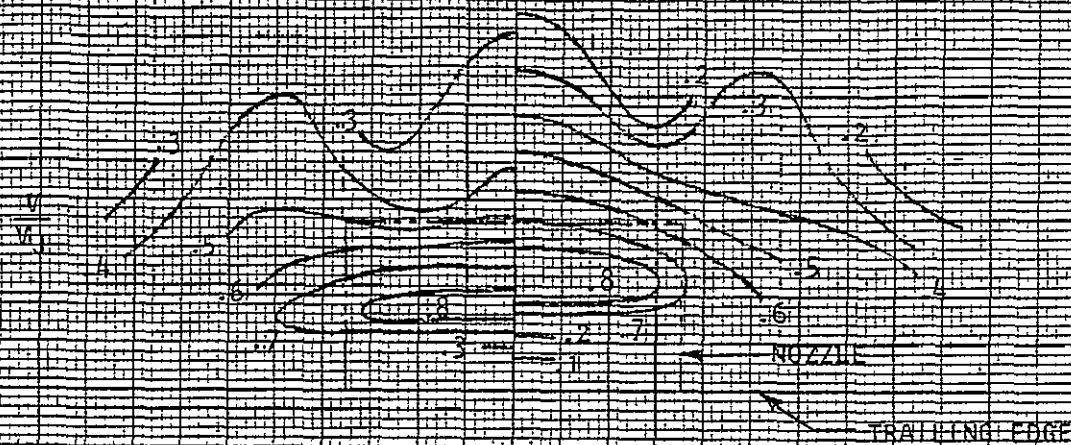


FIGURE 3-64. CONCLUDED.

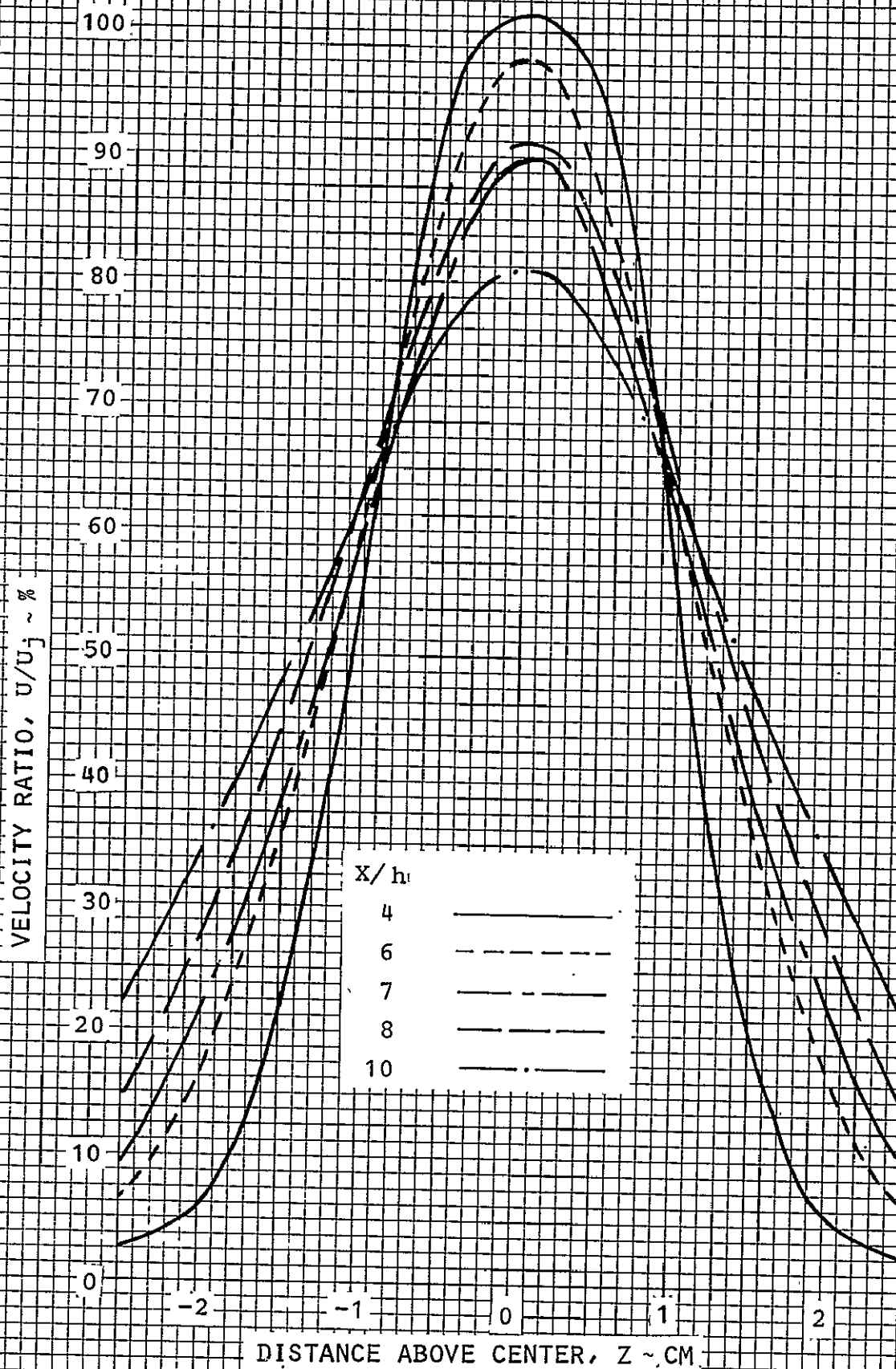


FIGURE 3-65. VELOCITY PROFILES DOWNSTREAM OF AR-8 NOZZLE ALONE. NPR = 1.10.

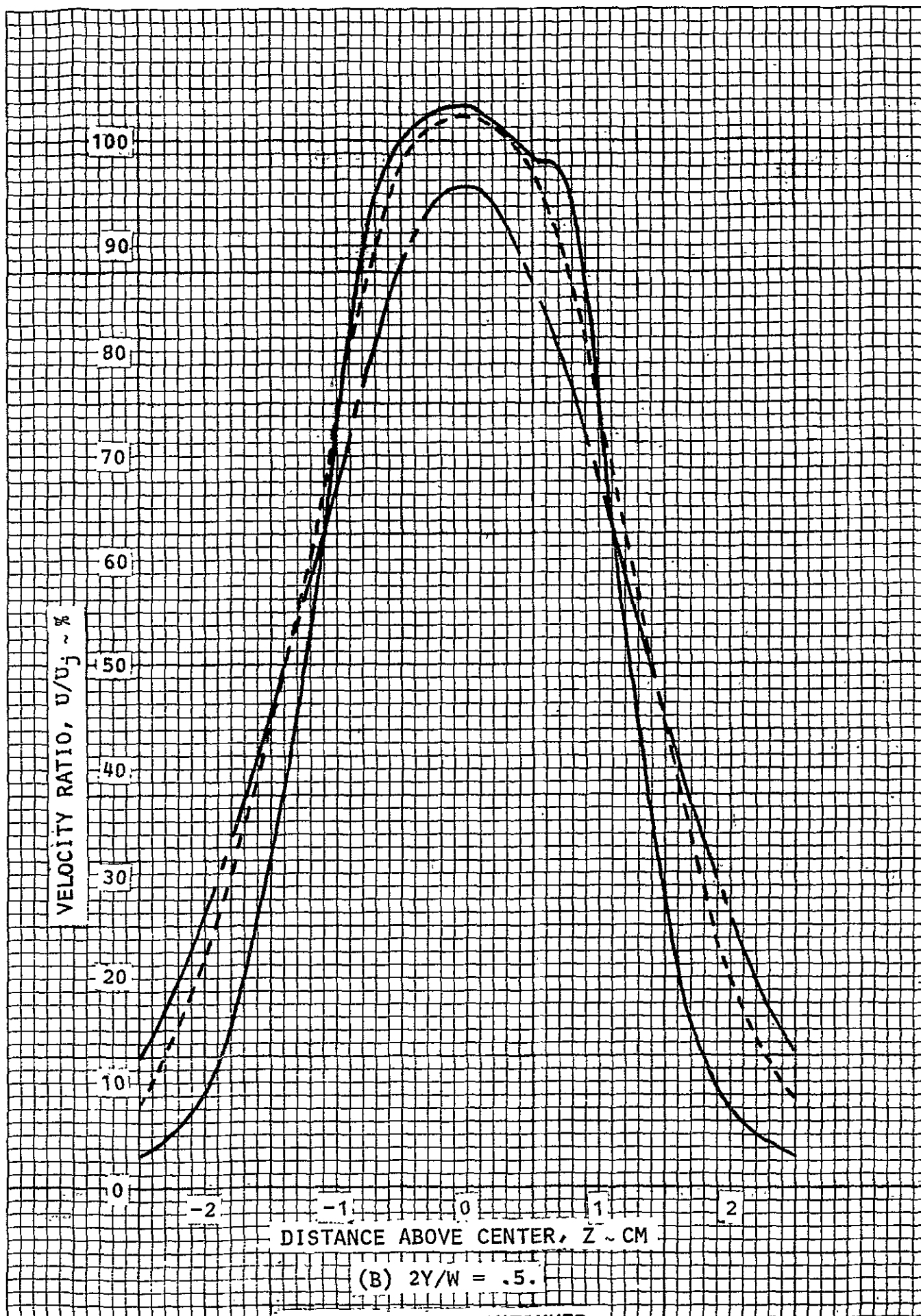
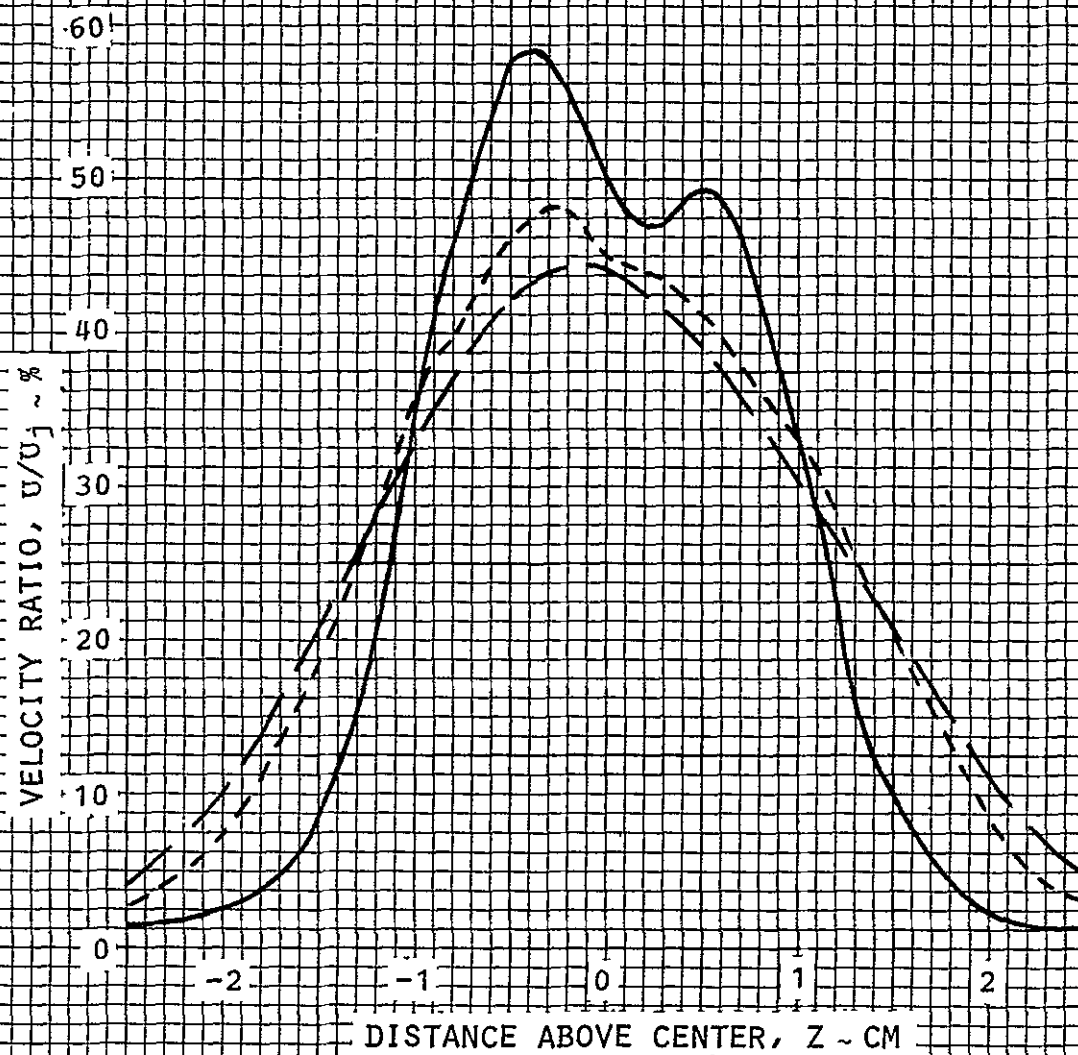
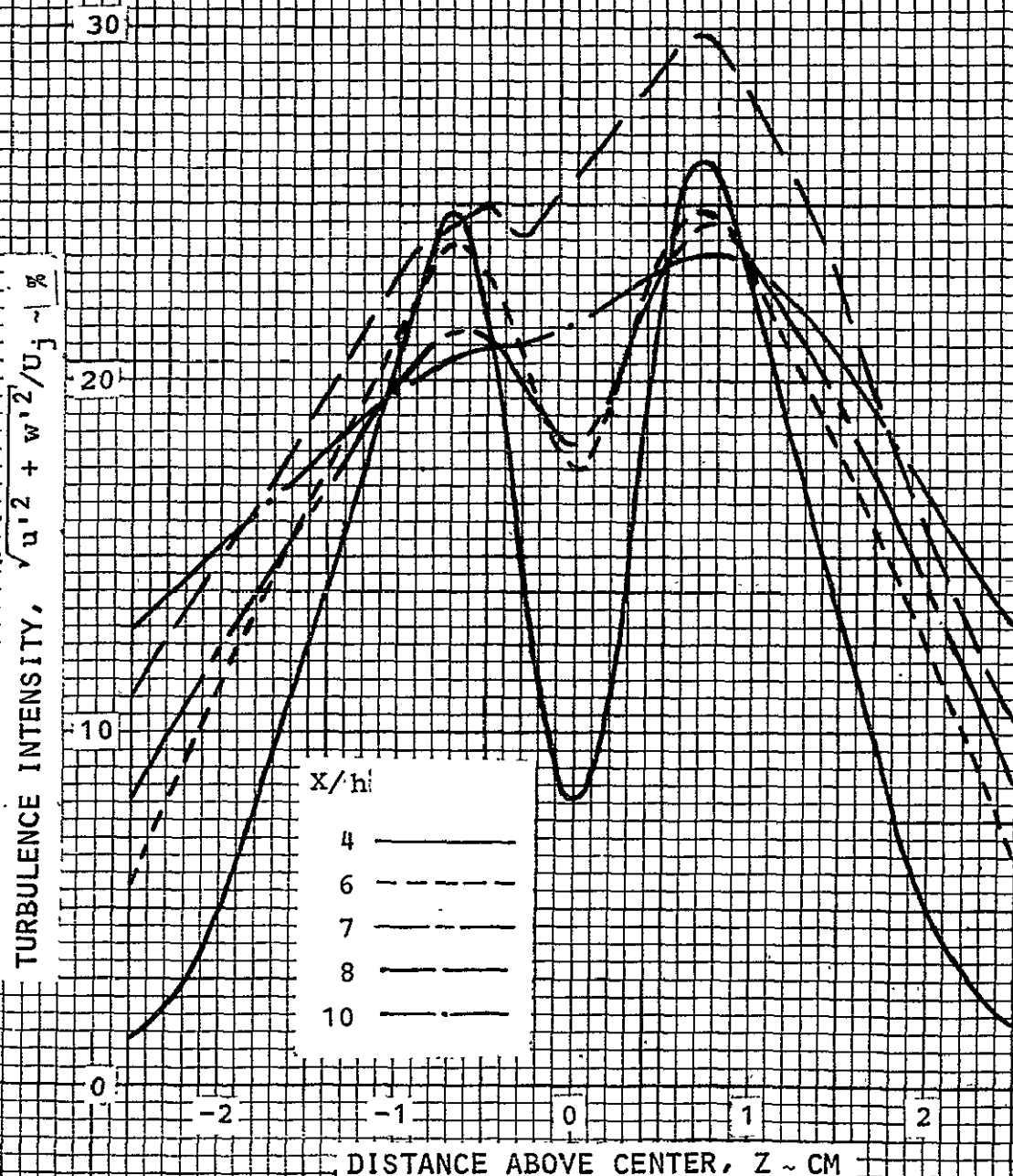


FIGURE 3-65, CONTINUED.



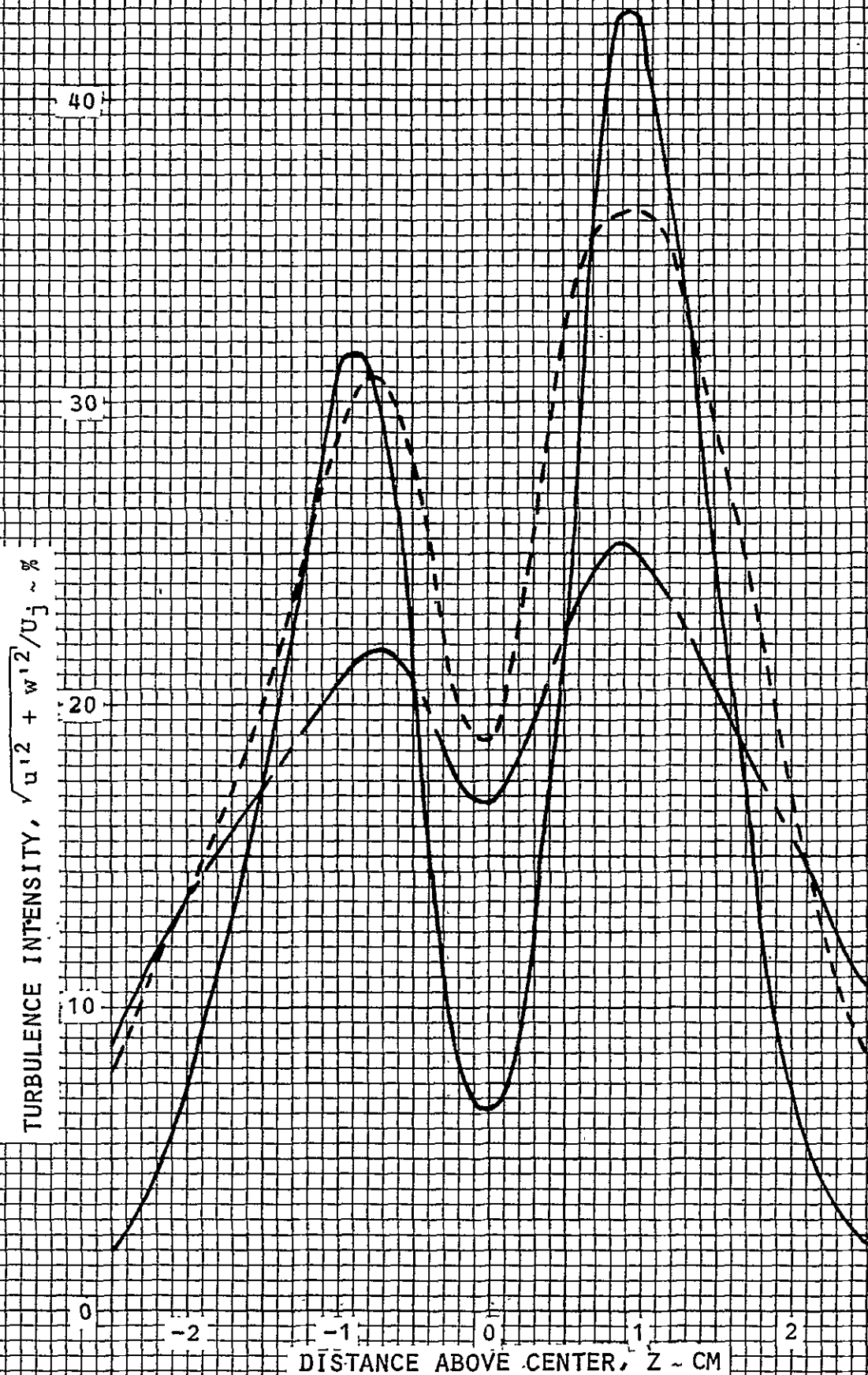
(C) $2Y/W = 1.0.$

FIGURE 3-65 , CONCLUDED.



(A) $2Y/W = 0.$

FIGURE 3-66. TURBULENCE PROFILES DOWNSTREAM OF AR-8 NOZZLE ALONE. NPR = 1.10.



(B) $2Y/W = .5$.

FIGURE 3-66. CONTINUED.

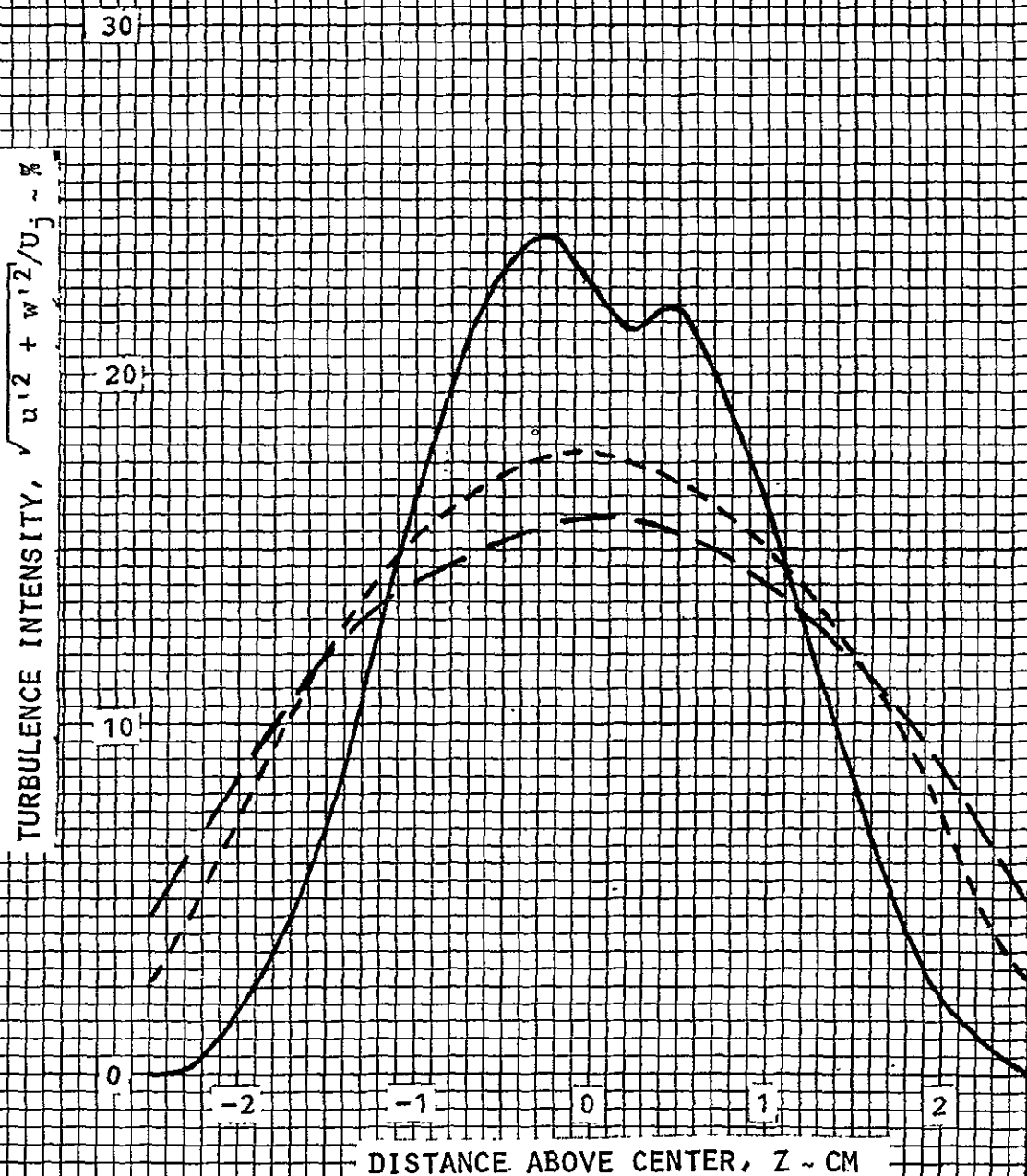
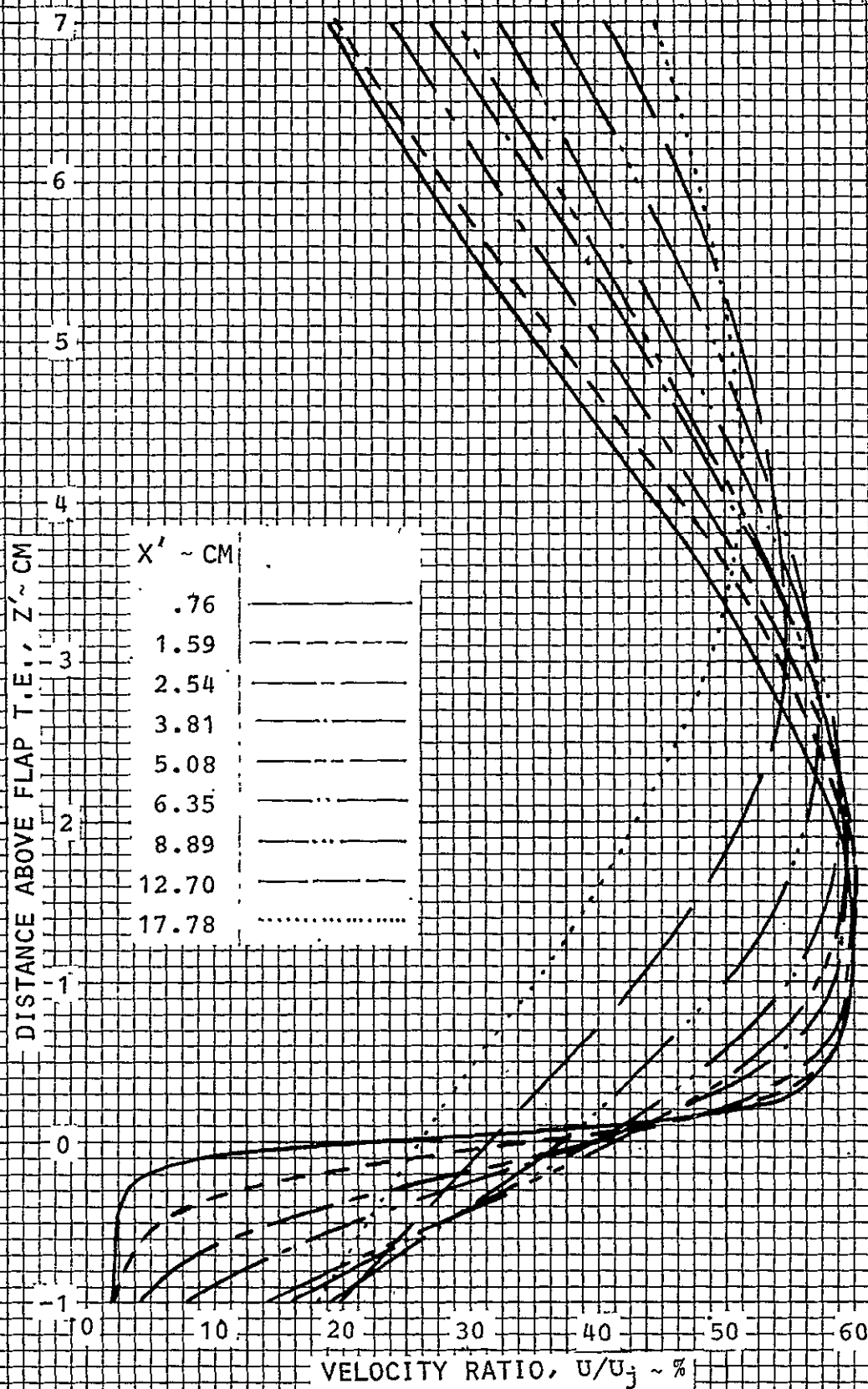


FIGURE 3-66, CONCLUDED.



(A) $2Y/W = 0$.

FIGURE 3-671. VELOCITY PROFILES DOWNSTREAM OF FLAP T.E. AR-8 NOZZLE;
 $12.73 \times 1.59 \text{ CM}$; $A_N = 20.27 \text{ CM}^2$; $X_N = .20C$; $\theta_N = 20^\circ$;
 $\text{NPR} = 1.10$; $R_N = 7.62 \text{ CM}$; $\delta_f = 60^\circ$; $\delta_r = 60^\circ$ CM

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DISTANCE ABOVE FLAP T.E., $Z' \sim \text{CM}$

7

6

5

4

3

2

1

0

-1

10

20

VELOCITY RATIO, $U/U_j \sim \%$

(B) $2Y/W = .5$

FIGURE 3-67, CONTINUED.

3-142

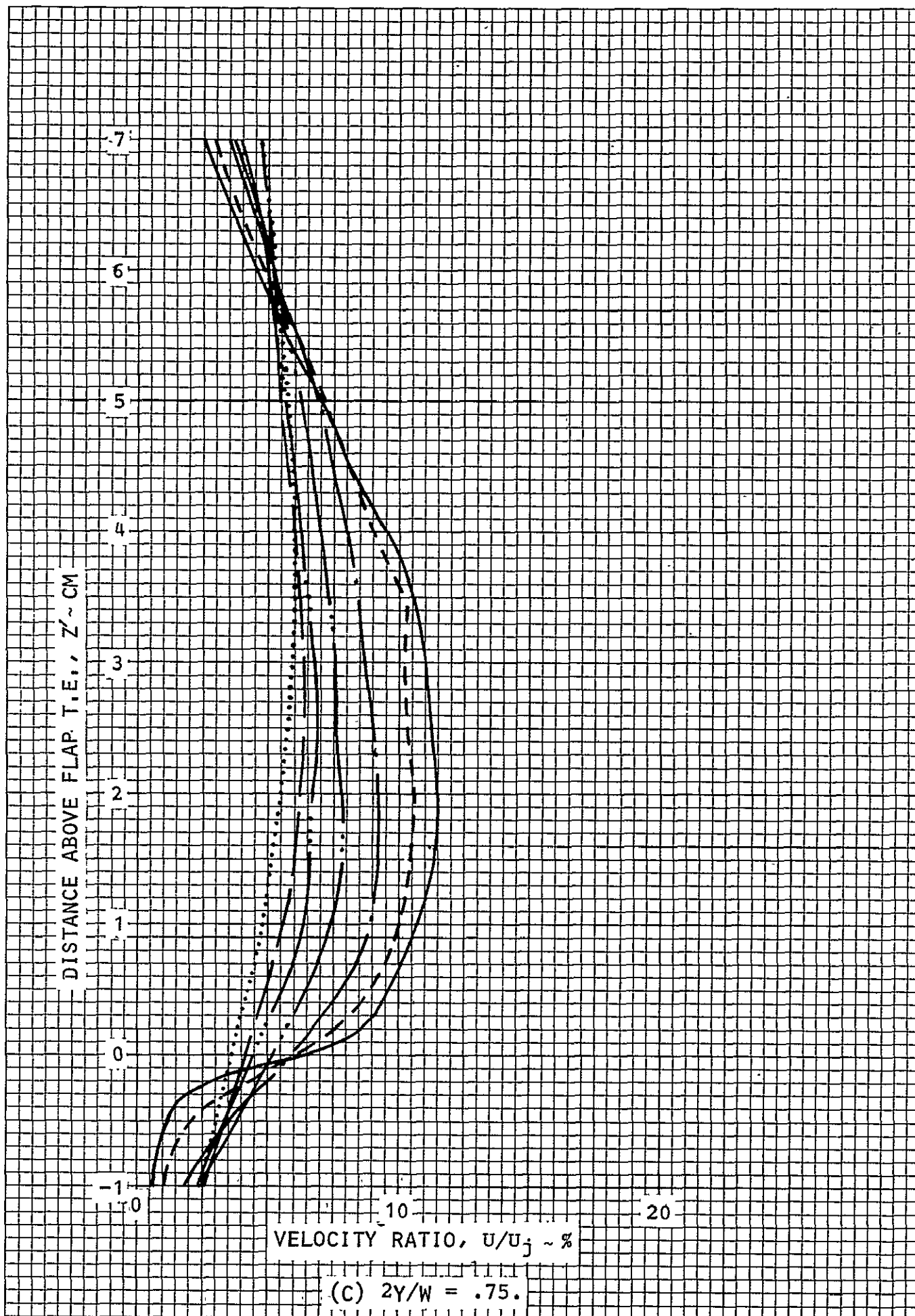


FIGURE 3-67, CONTINUED.

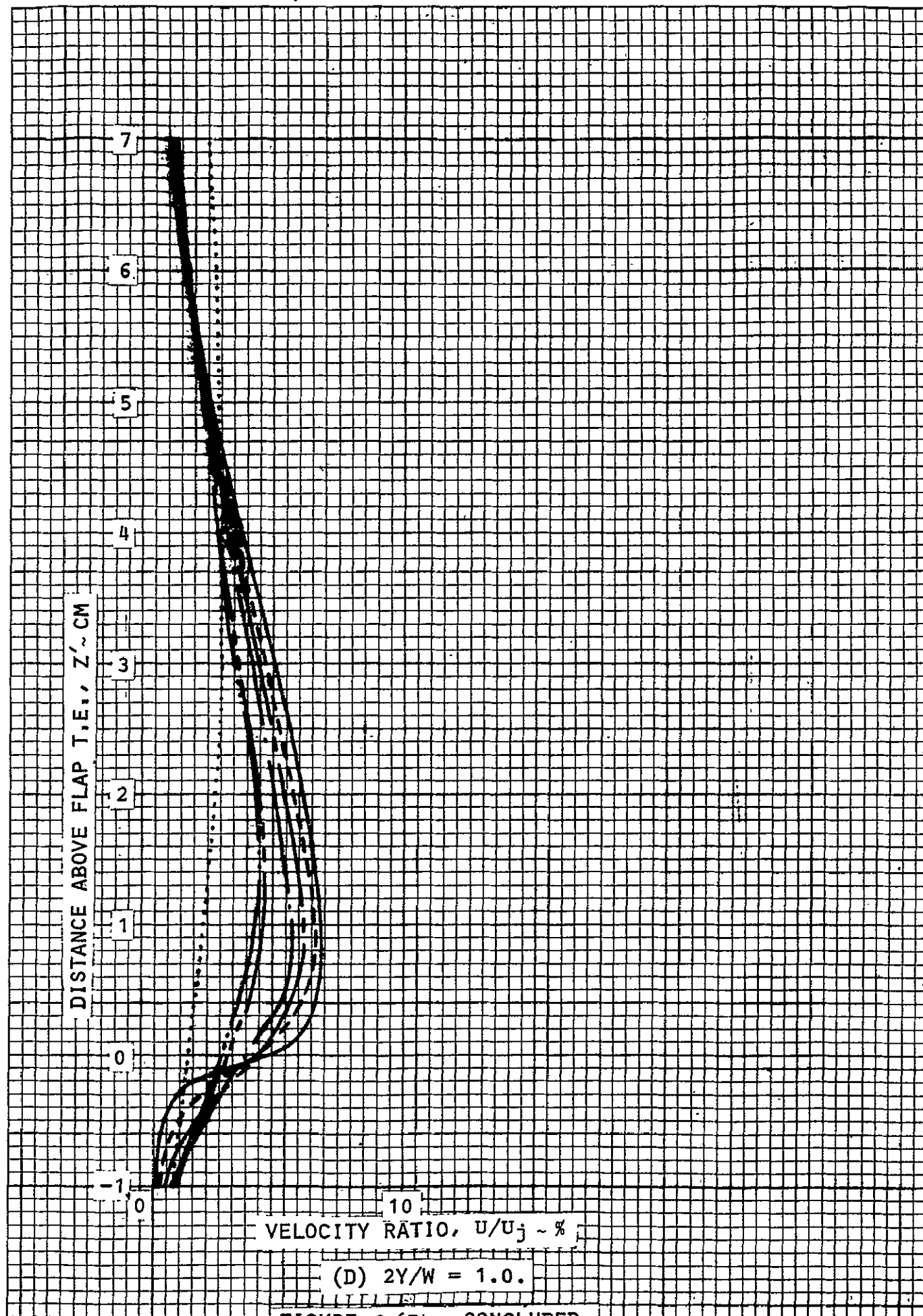


FIGURE 3-67. CONCLUDED.

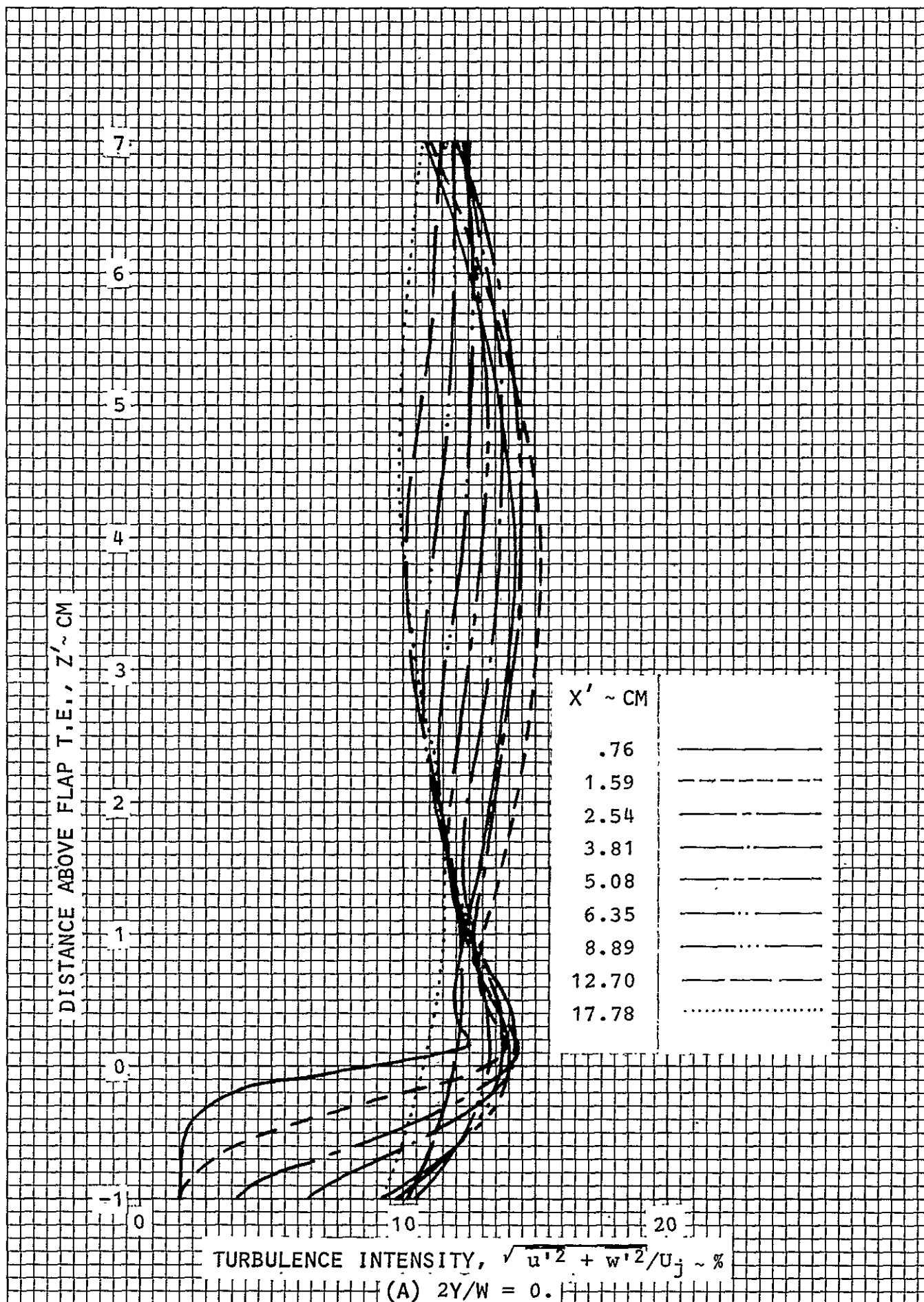


FIGURE 3-68'. TURBULENCE PROFILES DOWNSTREAM OF FLAP T.E. AR-8 NOZZLE;
 $12.73 \times 1.59 \text{ CM}$; $A_N = 20.27 \text{ CM}^2$; $X_N = .20C$; $\theta_N = 20^\circ$;
 $\text{NPR} = 1.10$; $R_C = 7.62 \text{ CM}$; $\delta_f = 60$; $L_{t.e.} = 6.48 \text{ CM}$.

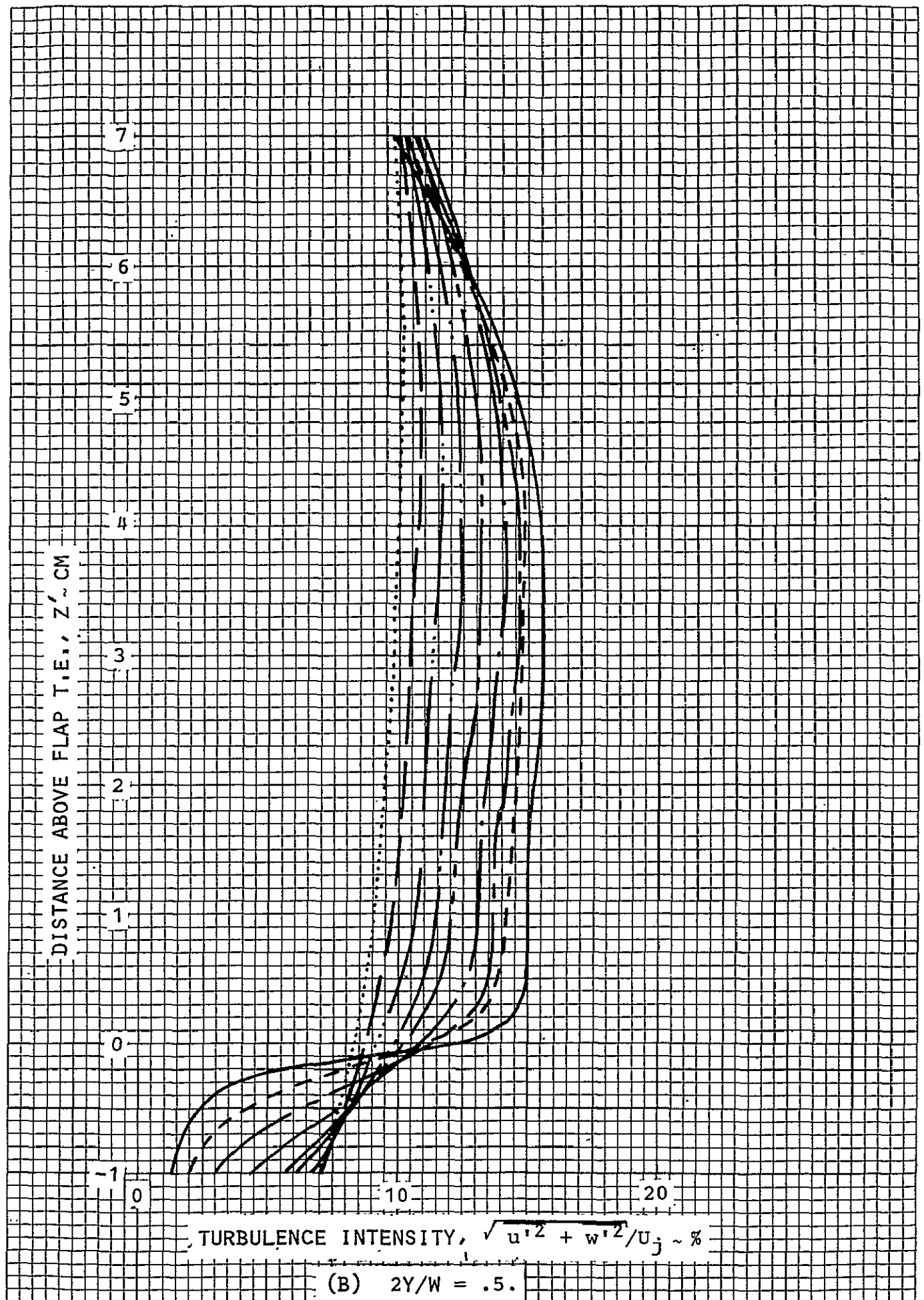
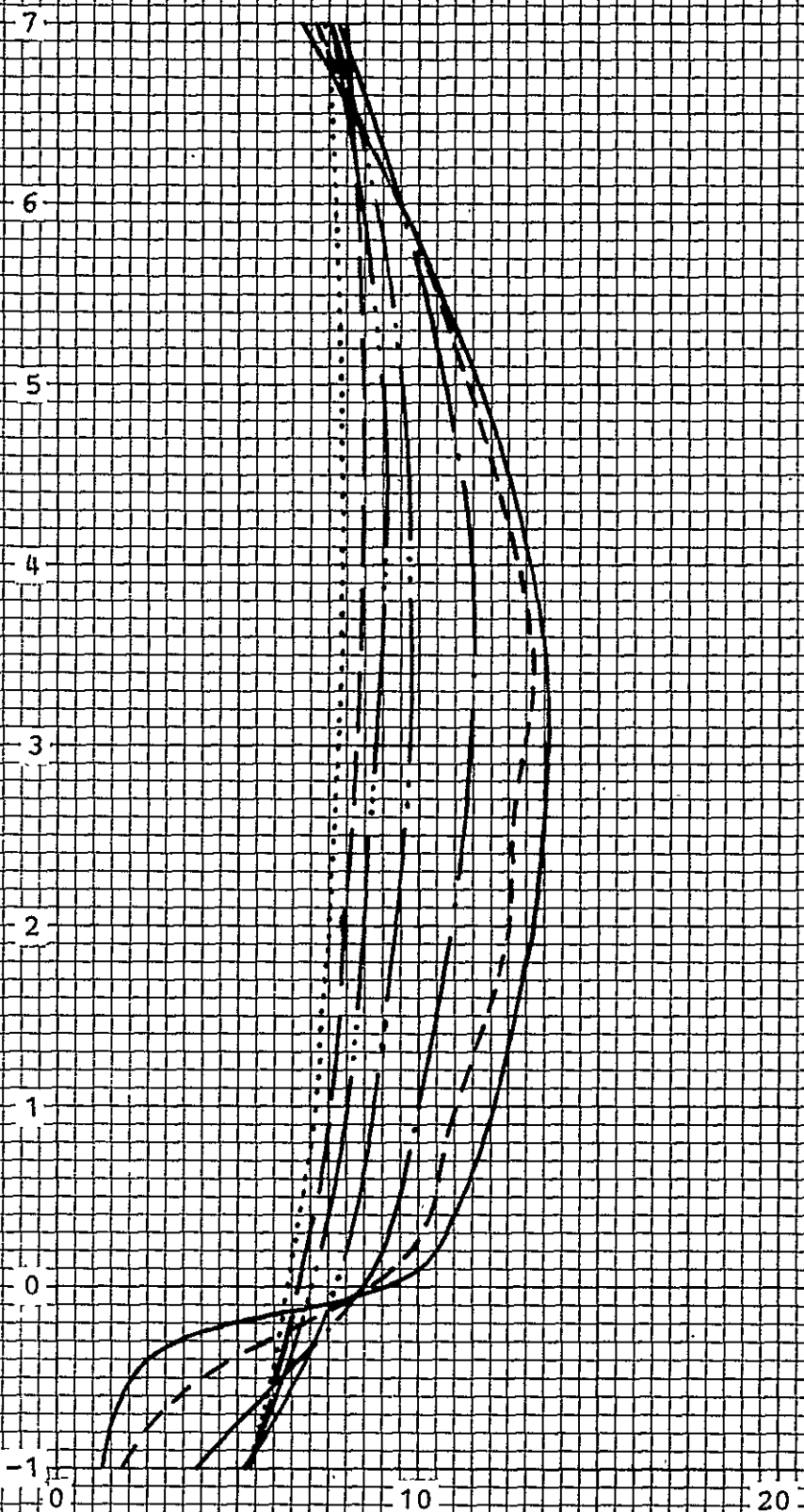


FIGURE 3-68., CONTINUED.

DISTANCE ABOVE FLAP T.E., $Z' \sim \text{CM}$



TURBULENCE INTENSITY, $\sqrt{u'^2 + w'^2}/U_j \sim \%$

(C) $2Y/W = .75$.

FIGURE 3-68, CONTINUED.

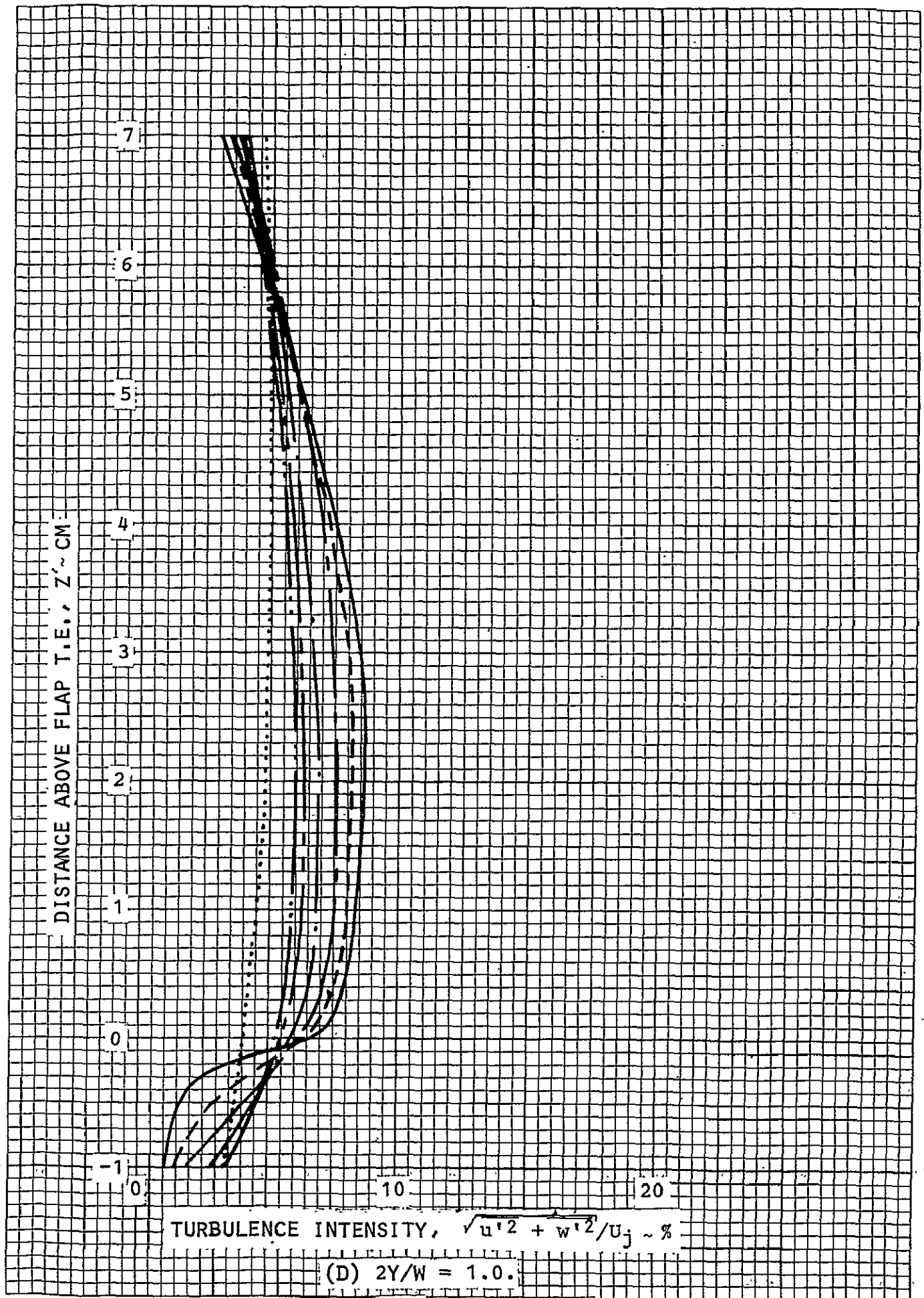


FIGURE 3-68. CONCLUDED.

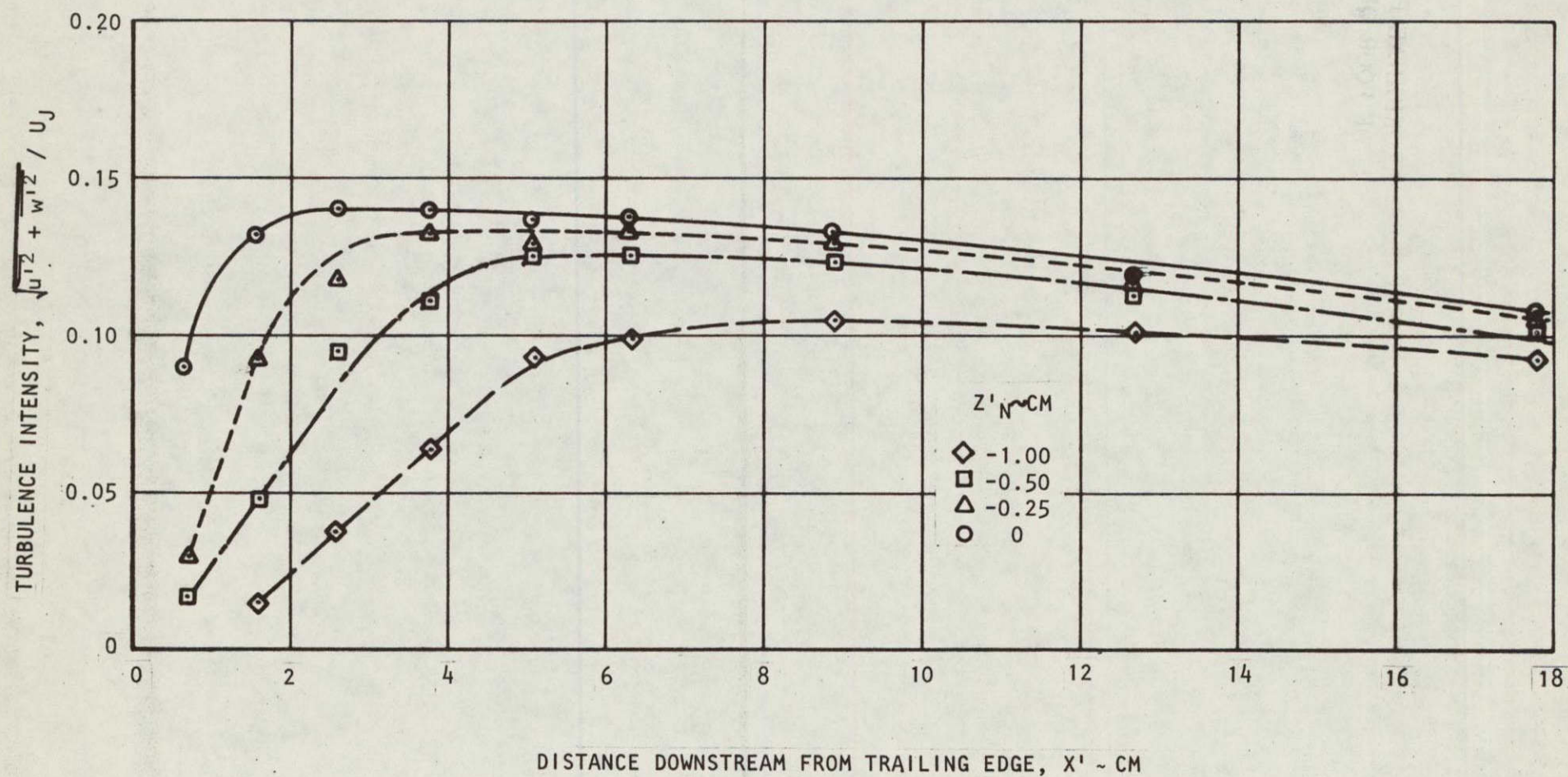
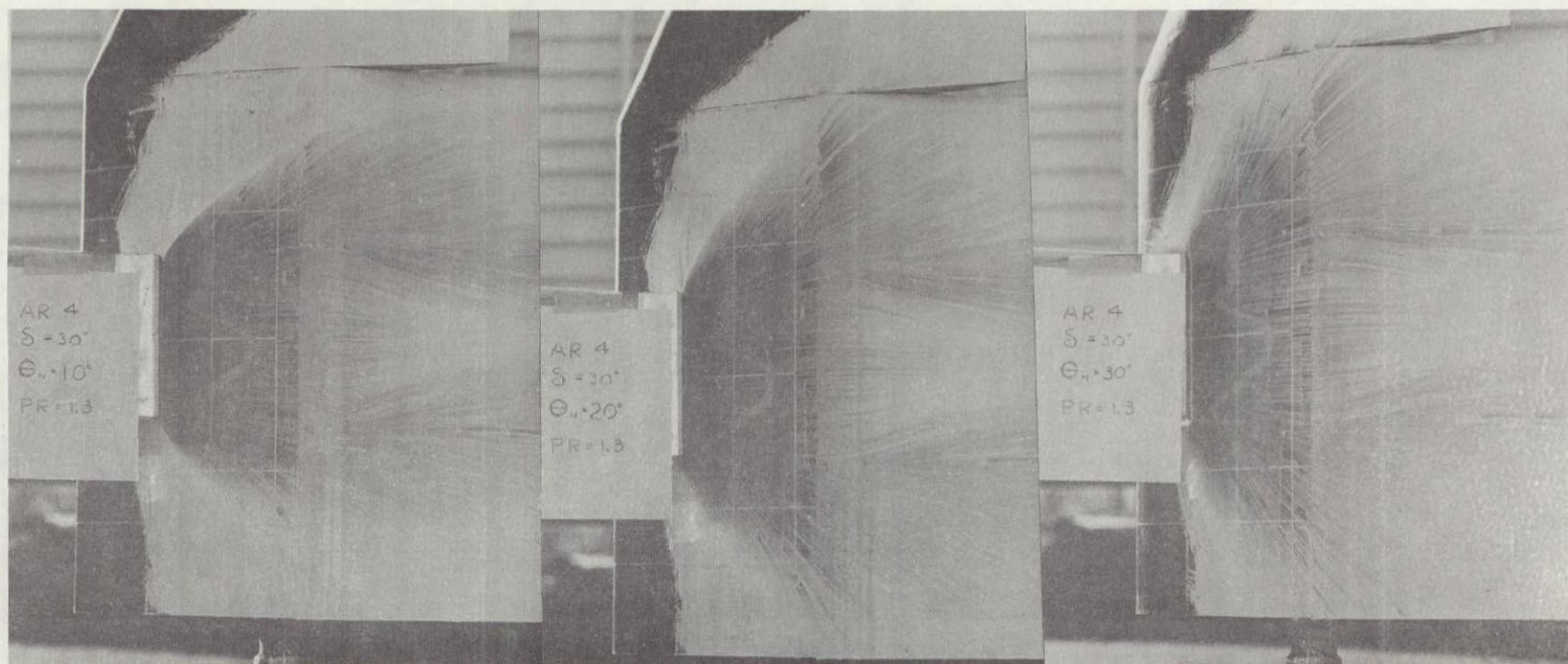


FIGURE 13-69. TURBULENCE INTENSITY DISTRIBUTION; AR-8 NOZZLE;
 $X_N = 0.20 \text{ c}$; $\theta_N = 20^\circ$; $\text{NPR} \approx 1.1$; $R_c = 7.62 \text{ cm}$;
 $\delta_f = 60^\circ$; $L_{te} = 6.48 \text{ cm}$, $Y = 0$



$\theta_N = 10^\circ$

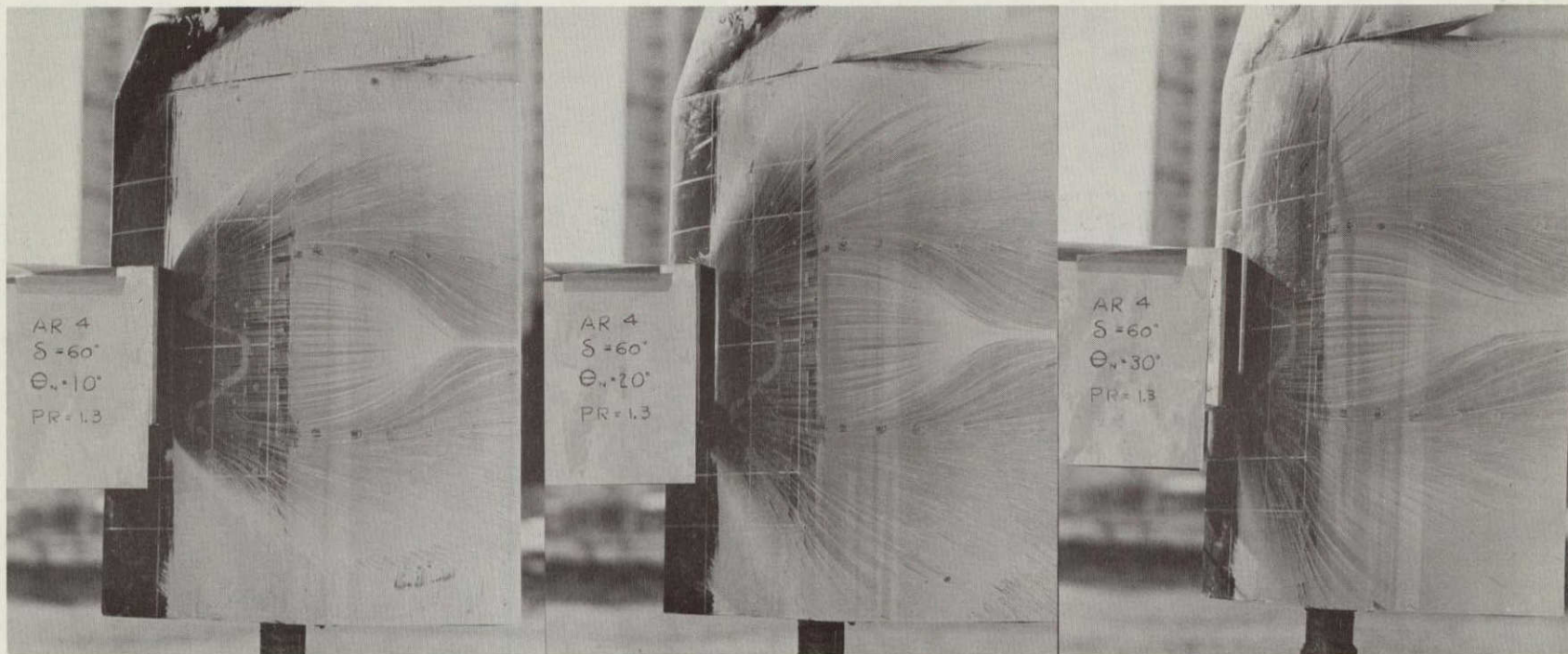
$\theta_N = 20^\circ$

$\theta_N = 30^\circ$

(A) $\delta_f = 30$; $L_{te} = 24.82$ CM

FIGURE 3-70. OIL FLOW PATTERNS, AR-4 NOZZLE. $X_N = .20C$;
 $R_C = 18.06$ CM; $Z_N = 0$; $NPR = 1.3$

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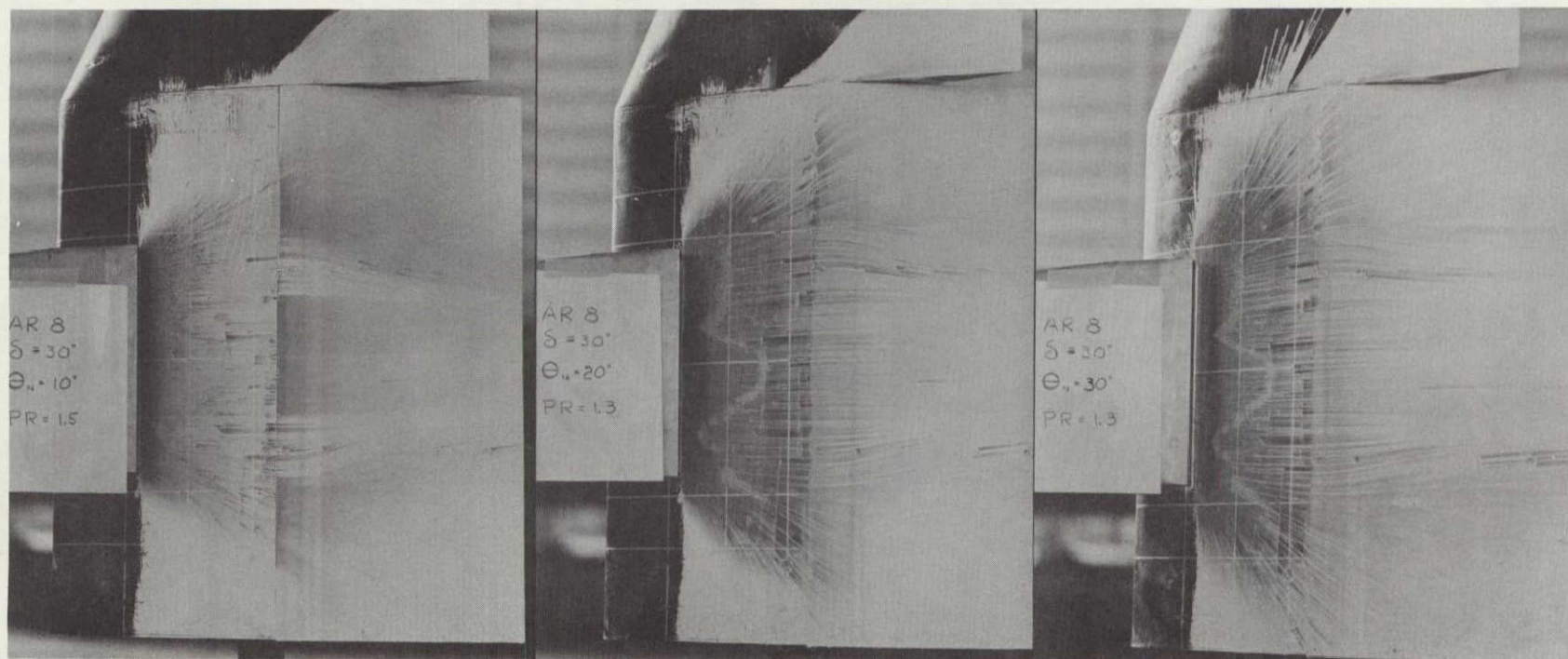
$$\theta_N = 10^\circ$$

$$\theta_N = 20^\circ$$

$$\theta_N = 30^\circ$$

(B) $\delta_f = 60$; $L_{te} = 15.34$ CM

FIGURE 3-70. (CONCLUDED).



$\theta_N = 10^\circ$
(NPR = 1.5)

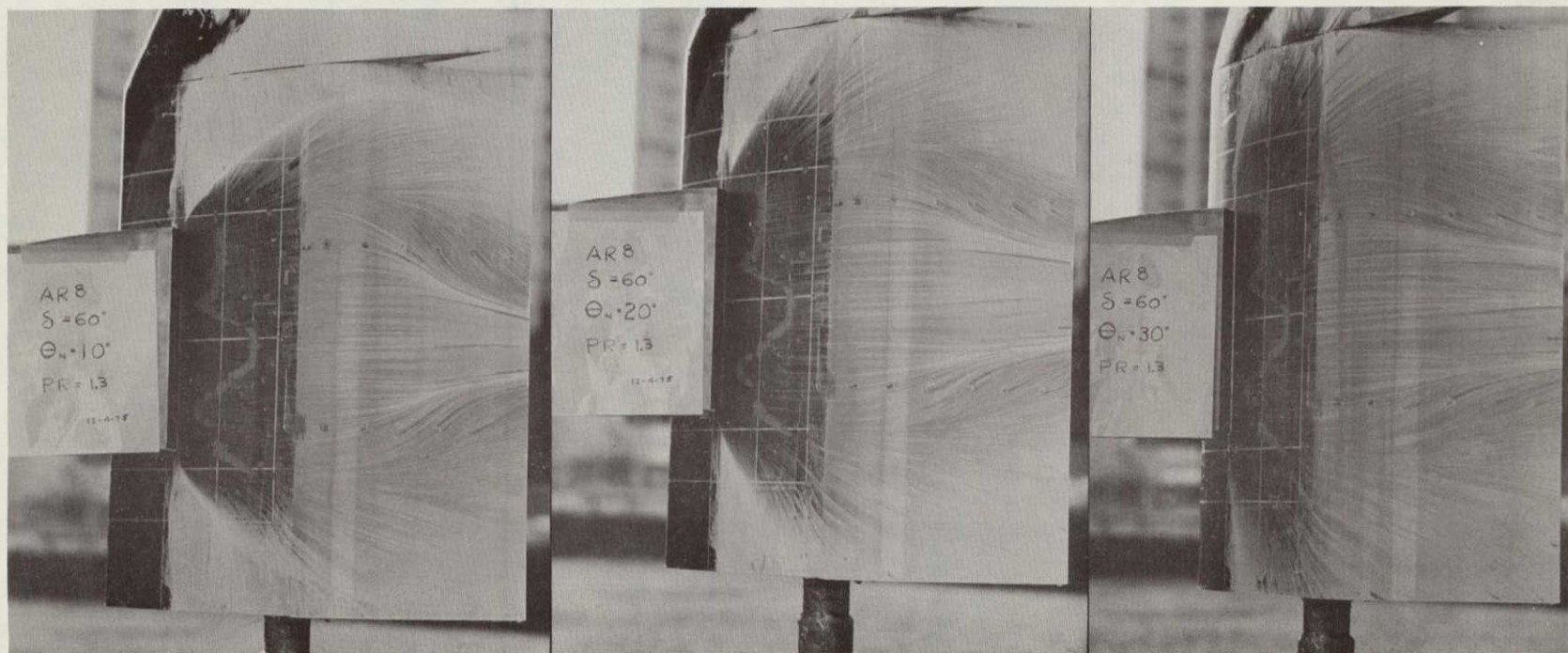
$\theta_N = 20^\circ$

$\theta_N = 30^\circ$

(A) $\delta_f = 30^\circ$; $L_{te} = 24.82$ CM

FIGURE 3-71. OIL FLOW PATTERNS, AR-8 NOZZLE. $X_N = .20C$;
 $R_C = 18.06$ CM; $Z_N = 0$; NPR = 1.3.

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$$\theta_N = 10^\circ$$

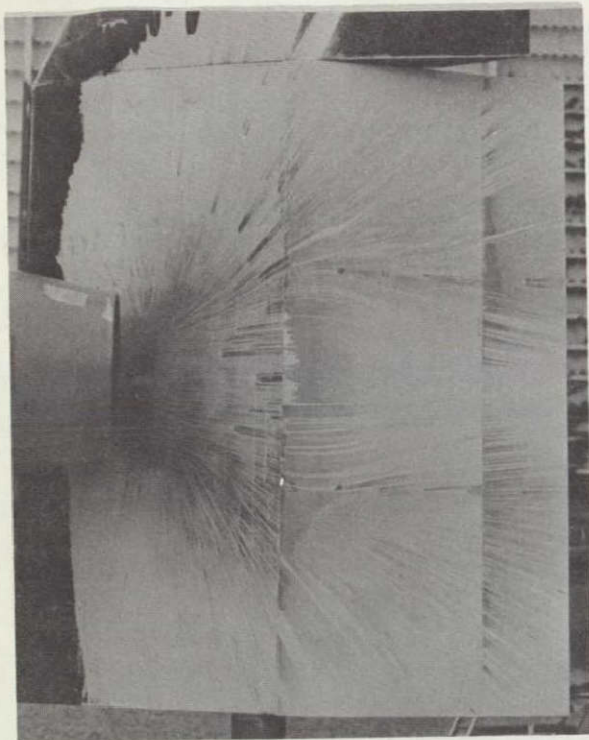
$$\theta_N = 20^\circ$$

$$\theta_N = 30^\circ$$

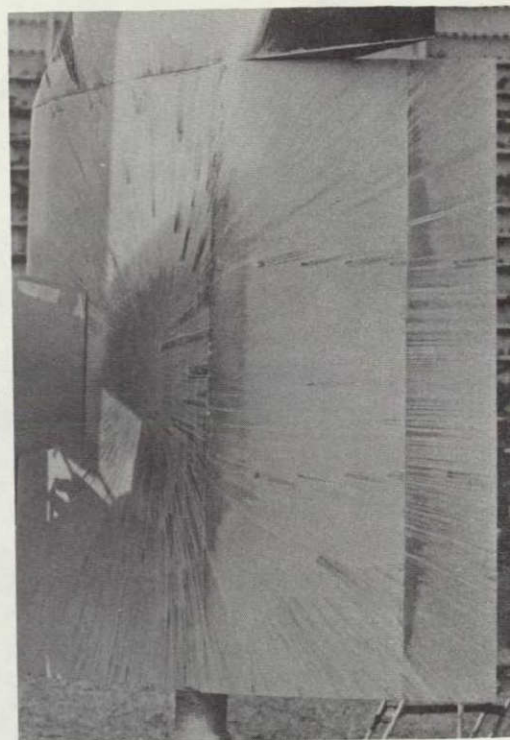
(B) $\delta_f = 60^\circ$; $L_{te} = 15.34$ CM

FIGURE 3-71. (CONCLUDED).

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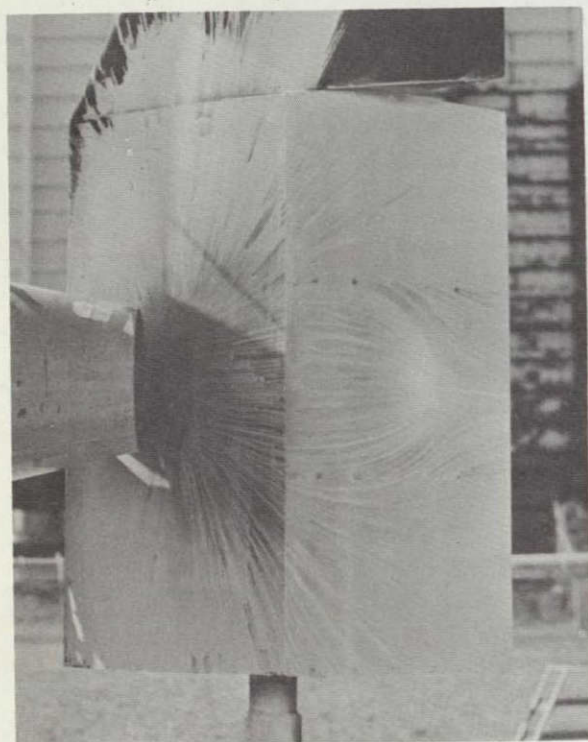


$\theta_N = 20^\circ; Z_N = 0$

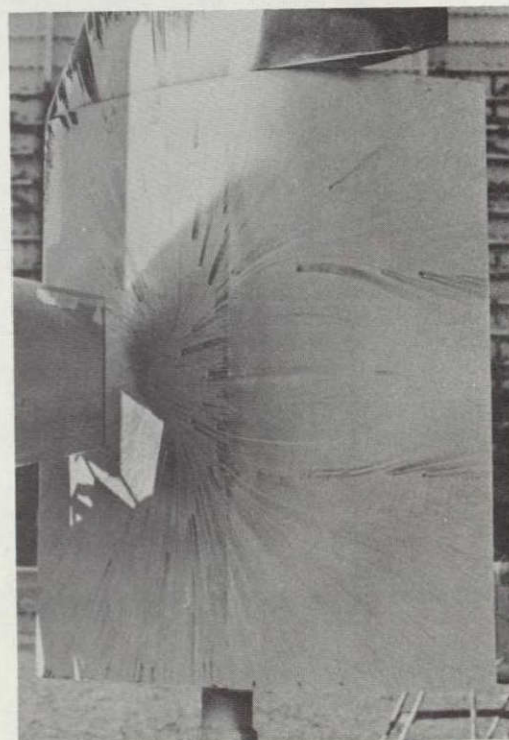


$\theta_N = 40^\circ; Z_N = 5.59 \text{ CM}$

(A) $\delta_f = 30^\circ; L_{te} = 24.82 \text{ CM.}$



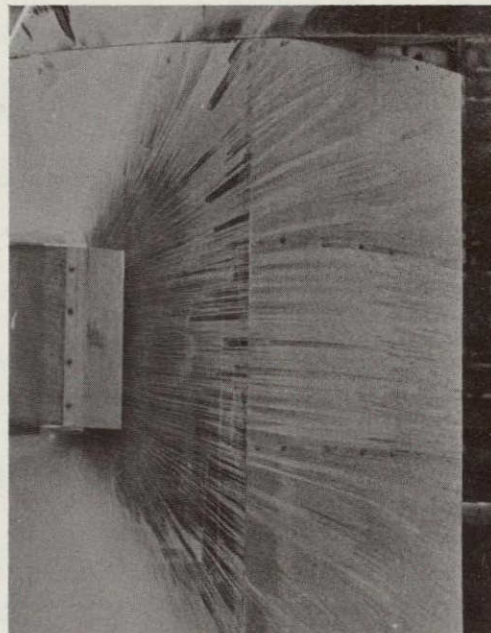
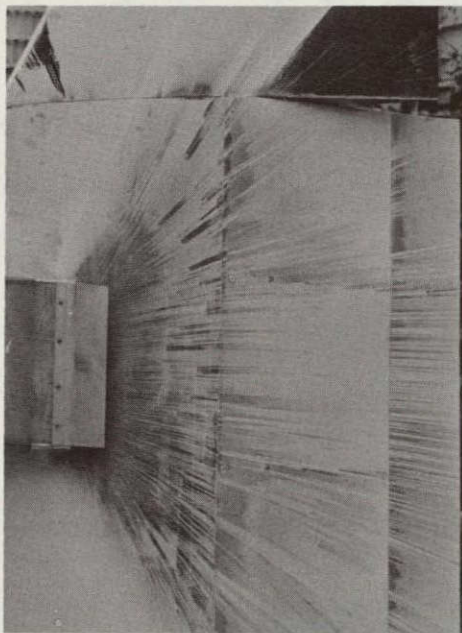
$\theta_N = 20^\circ; Z_N = 0$



$\theta_N = 40^\circ; Z_N = 5.59 \text{ CM}$

(B) $\delta_f = 60^\circ; L_{te} = 15.34 \text{ CM.}$

FIGURE 3-72. OIL FLOW PATTERNS, CIRCULAR NOZZLE. $X_N = .20C$;
 $R_C = 18.06 \text{ CM}$; $NPR = 1.44$.



$\delta_f = 30^\circ$; $L_{te} = 24.82$ CM

$\delta_f = 60^\circ$; $L_{te} = 15.34$ CM

FIGURE 3-73 . OIL FLOW PATTERNS, AR-4 NOZZLE WITH DEFLECTOR.
 $X_N = .20C$; $R_C = 18.06$ CM; $Z_N = 0$; $NPR = 1.44$.

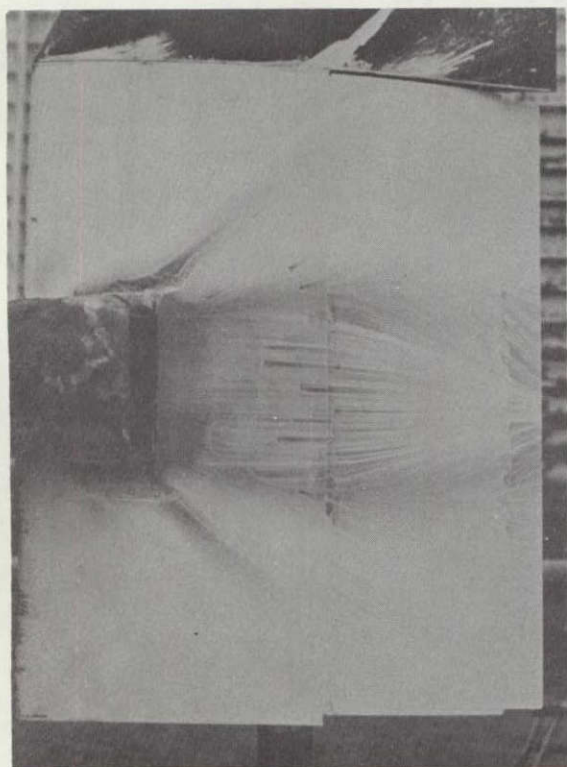
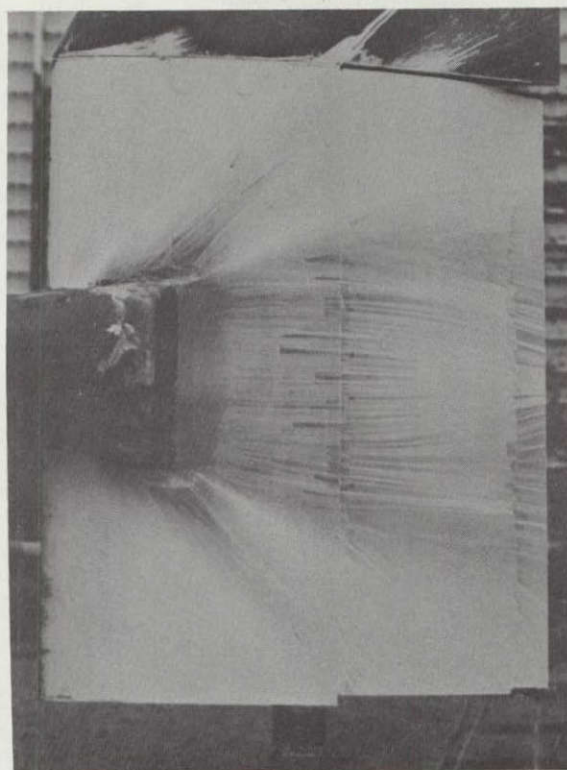
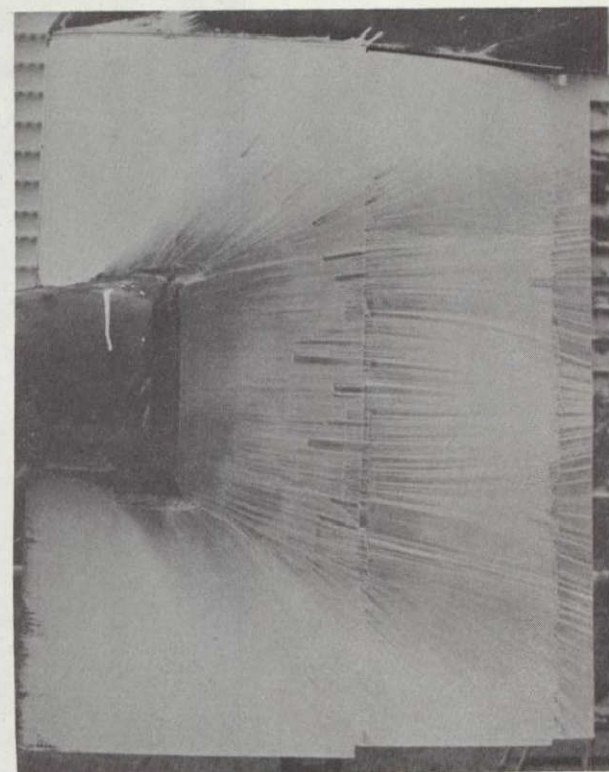
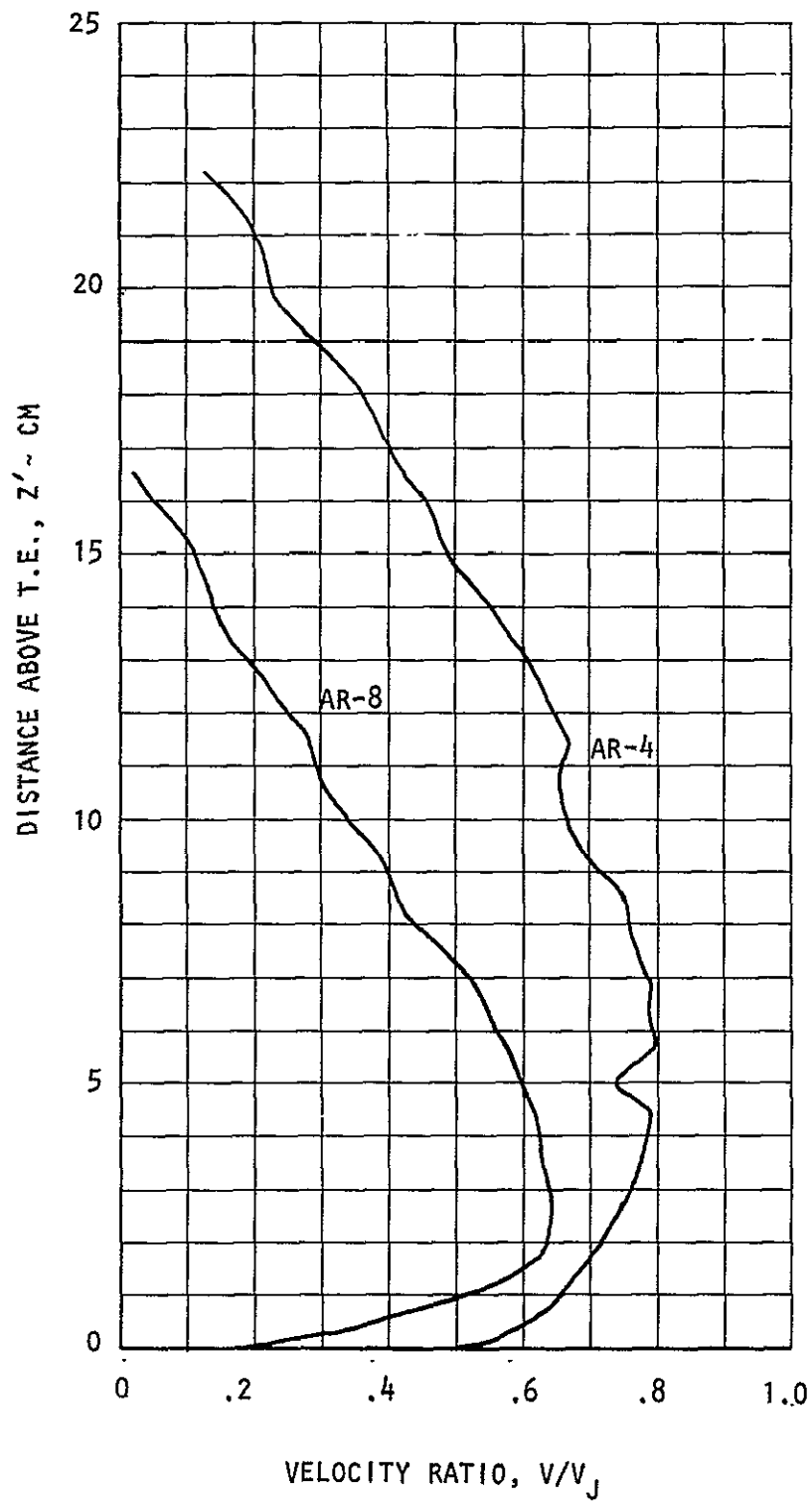
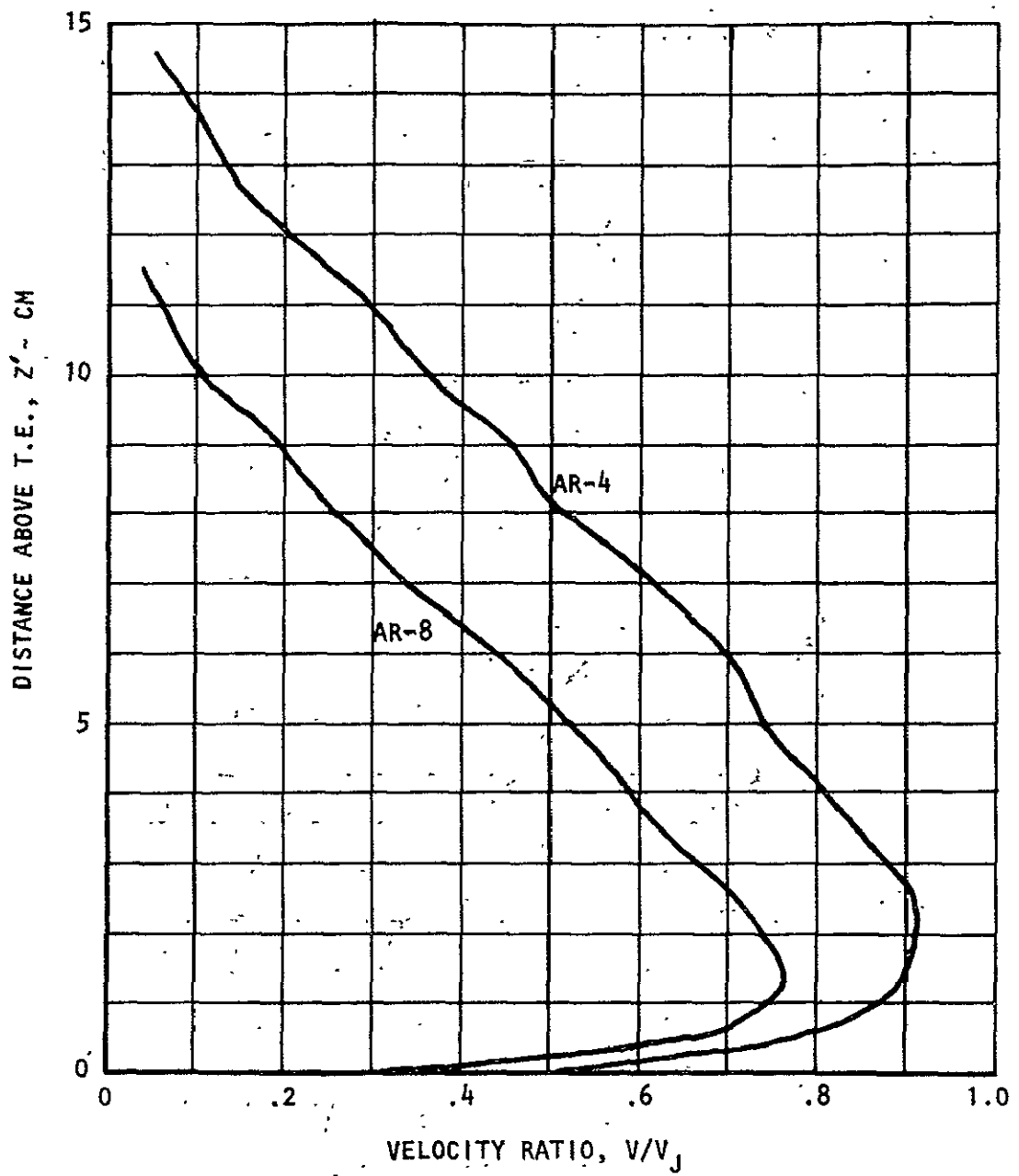
DOOR ANGLE = 0° DOOR ANGLE = 15° DOOR ANGLE = 25°

FIGURE 3-74. OIL FLOW PATTERNS, QCSEE NOZZLE. $X_N = .20C$;
 $R_C = 18.06$ CM; $\delta_f = 30^\circ$; $L_{te} = 24.82$ CM; $Z_N = 0$, $NPR = 1.44$.



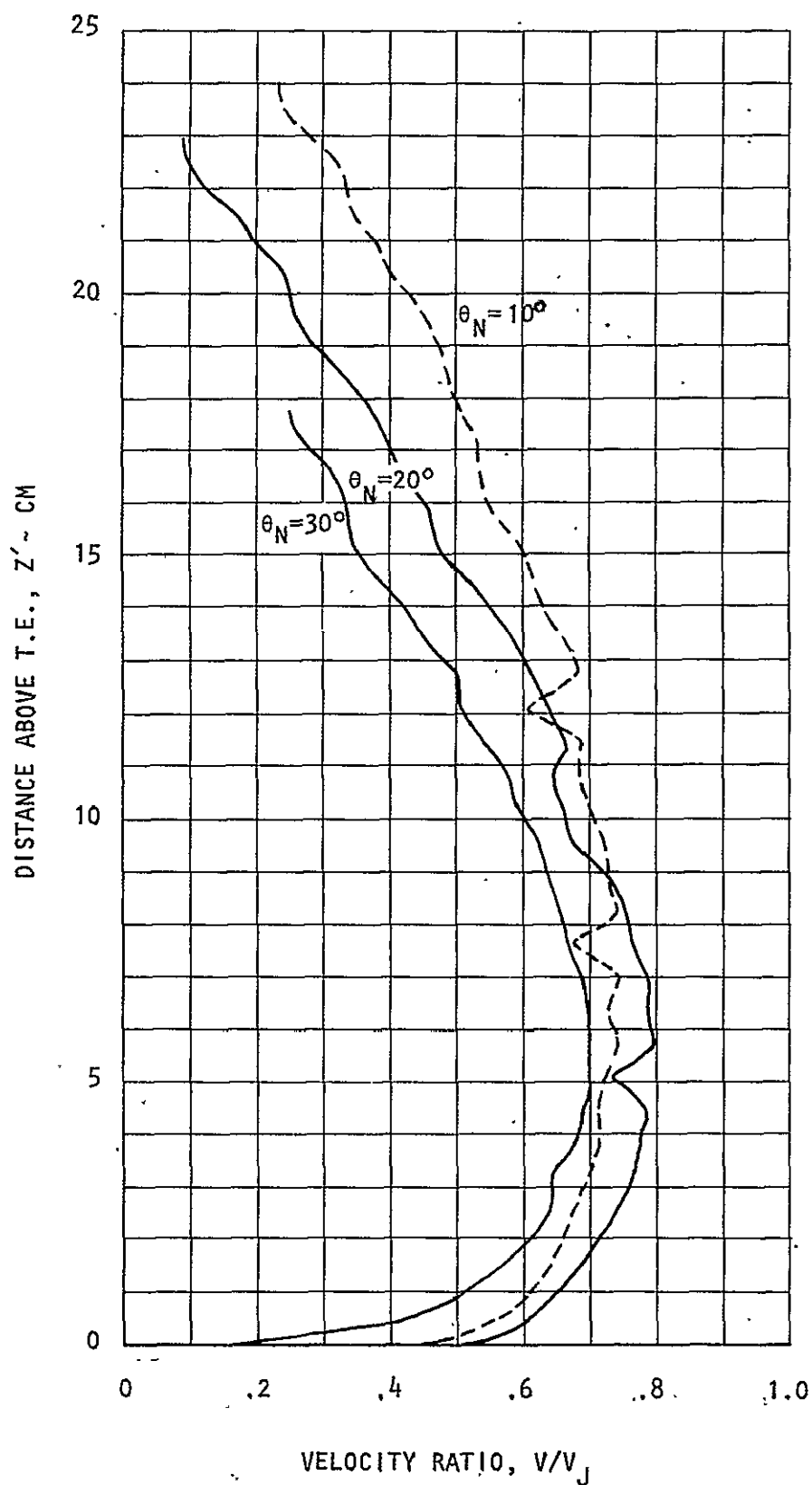
(A) EFFECT OF NOZZLE ASPECT RATIO. $\theta_N=20^\circ$; $\delta_F=60^\circ$; $L_{T.E.}=15.34$ CM.

FIGURE 3-75. TRAILING EDGE VELOCITY PROFILE COMPARISONS AT NOZZLE CENTERLINE. $X_N=.20C$; $R_C=18.06$ CM; $NPR = 1.5-1.6$.

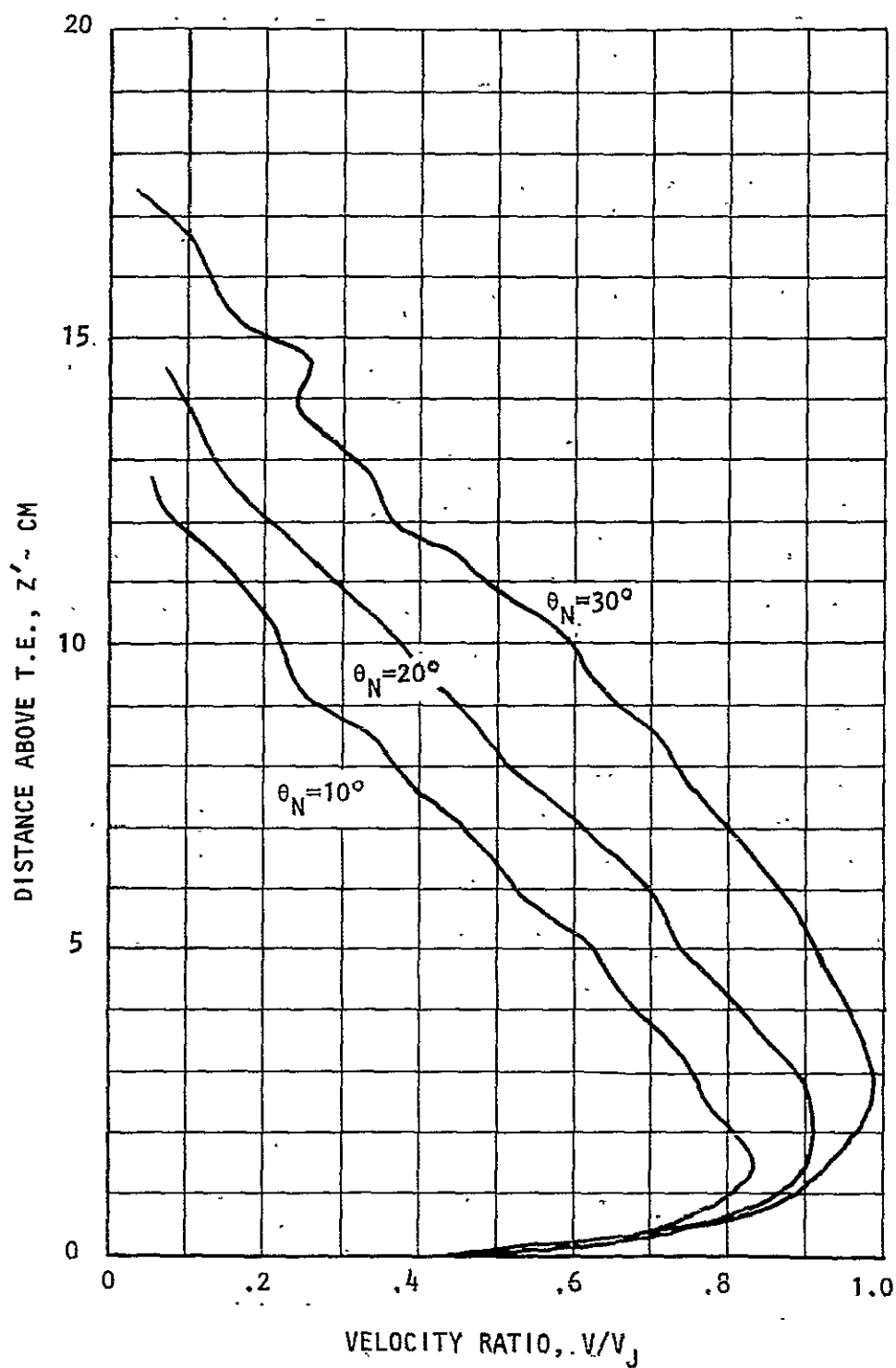


(B) EFFECT OF NOZZLE ASPECT RATIO. $\theta_N = 20^\circ$; $\delta_F = 30^\circ$; $L_{T.E.} = 24.82$ CM.

FIGURE 3-75. CONTINUED.

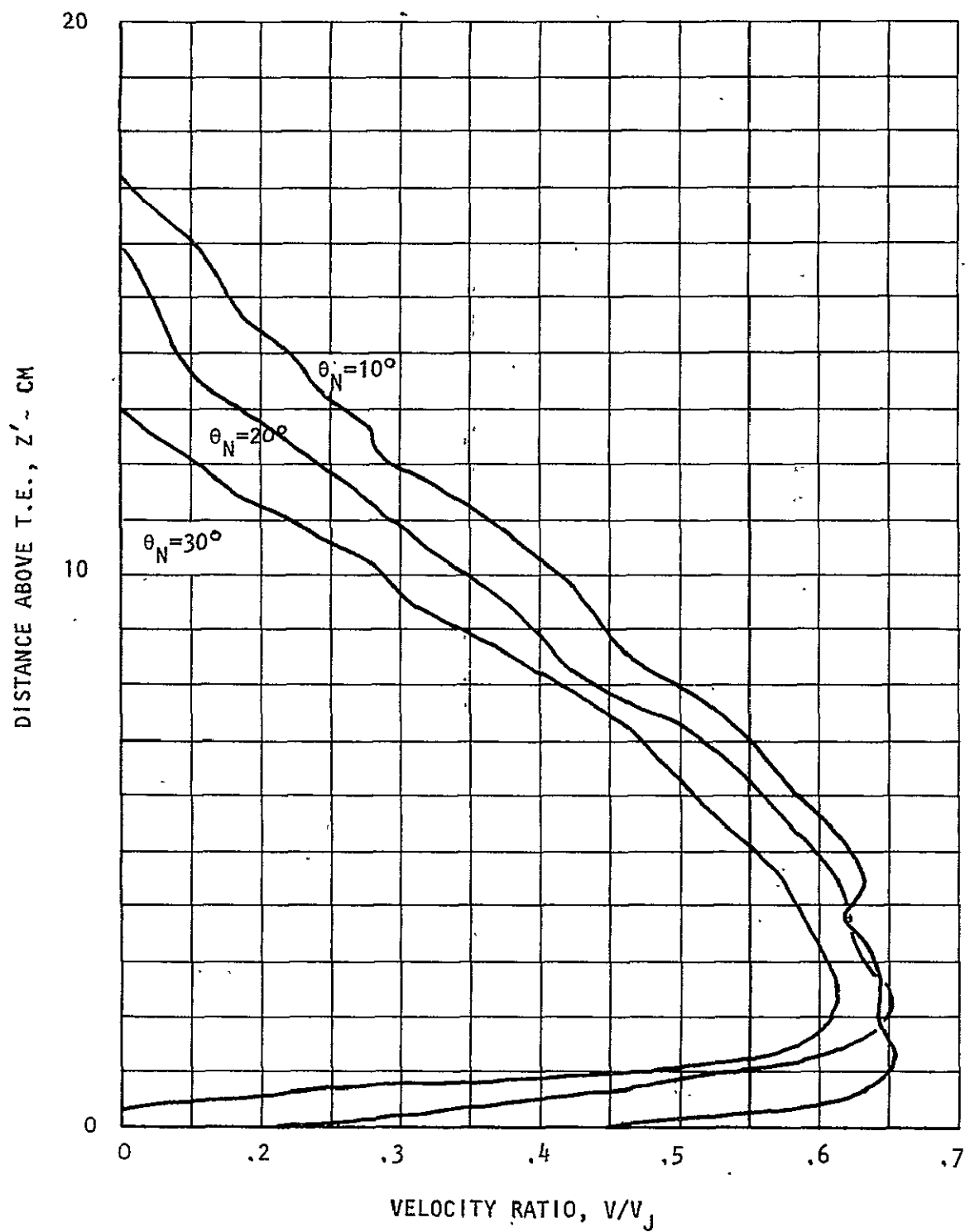


(C) EFFECT OF IMPINGEMENT ANGLE. AR-4 NOZZLE; $\delta_F = 60^\circ$; $L_{T.E.} = 15.34$ CM
FIGURE 3-75. CONTINUED.



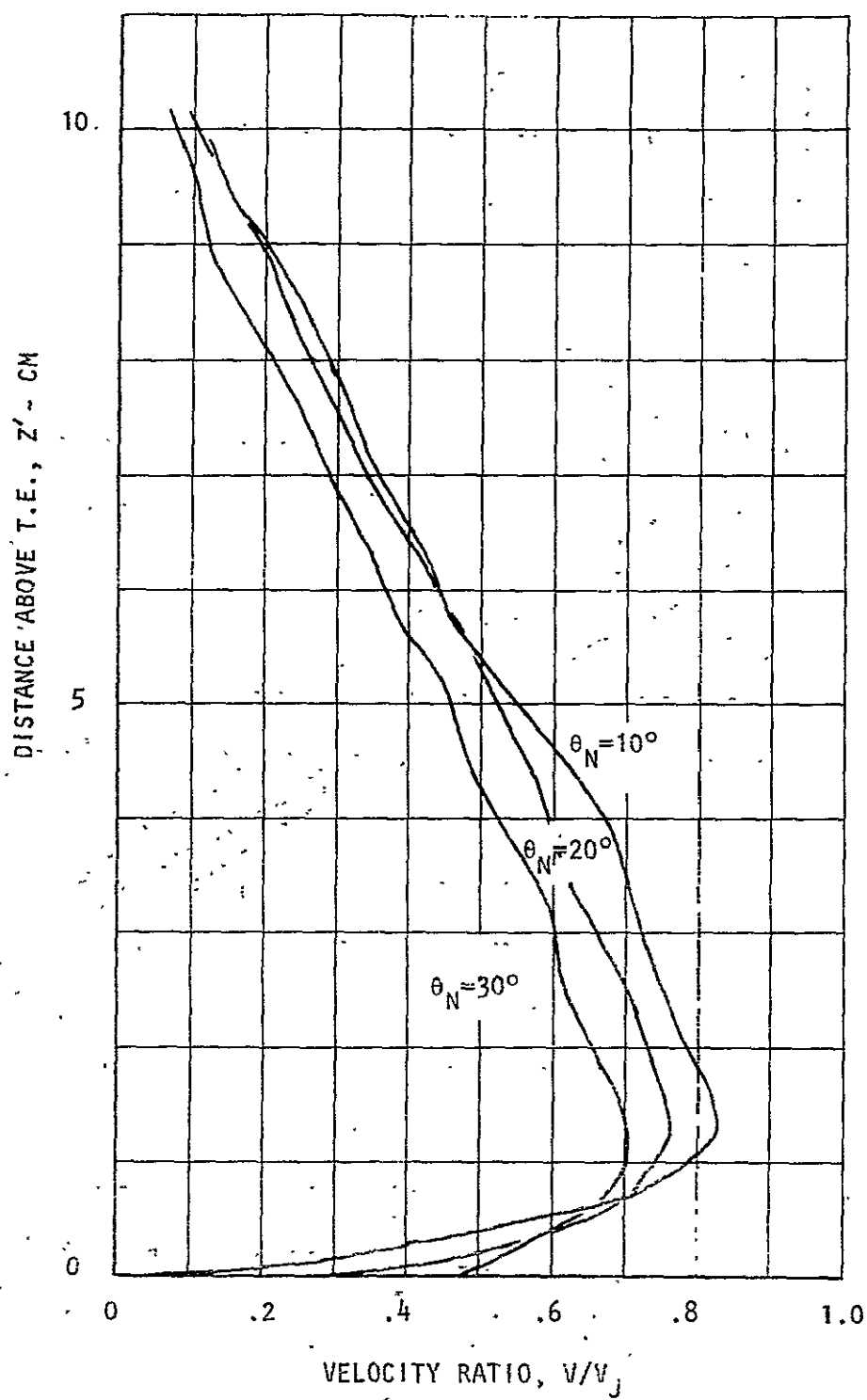
(D) EFFECT OF IMPINGEMENT ANGLE. AR-4 NOZZLE; $\delta_F = 30^\circ$; $L_{T.E.} = 24.82$ CM

FIGURE 3-75. CONTINUED.



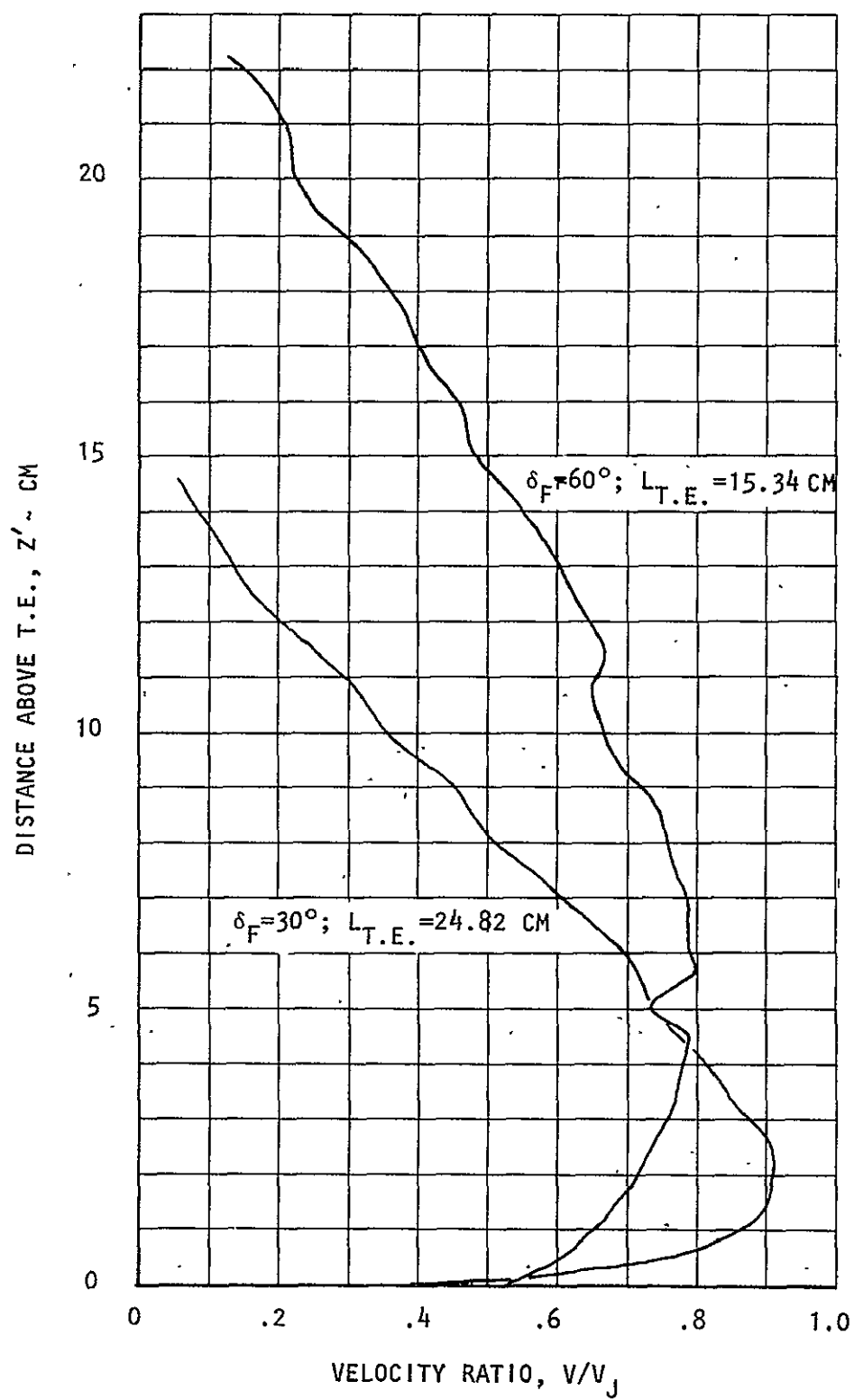
(E) EFFECT OF IMPINGEMENT ANGLE. AR-8 NOZZLE; $\delta_F = 60^\circ$; $L_{T.E.} = 15.34 \text{ cm}$.

FIGURE 3-75. CONTINUED.



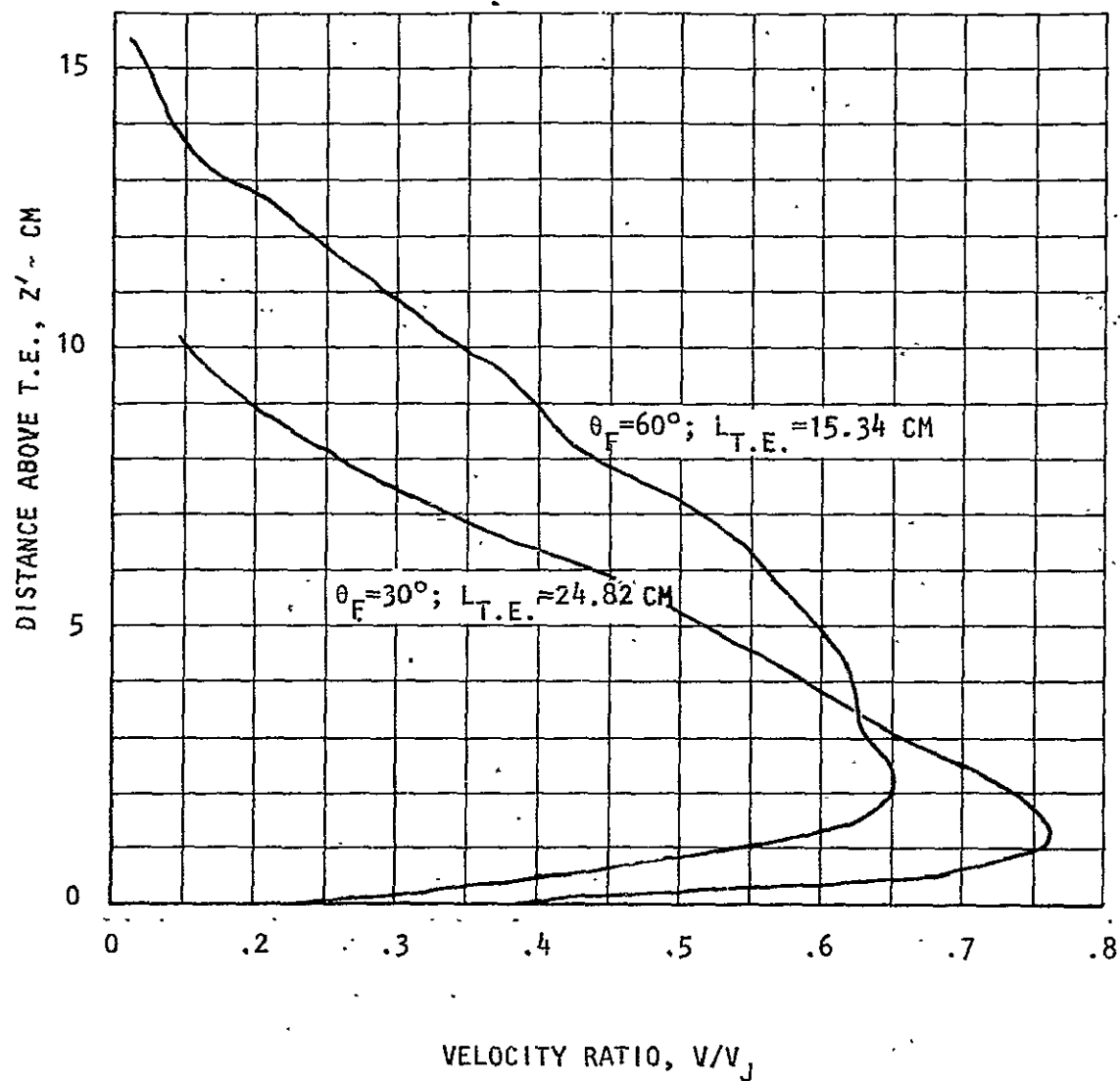
(F) EFFECT OF IMPINGEMENT ANGLE. AR-8 NOZZLE; $\delta_F \approx 30^\circ$; $L_{T.E.} = 24.82$ CM

FIGURE 3-75. CONTINUED.



(G) EFFECT OF FLAP ANGLE. AR=4 NOZZLE; $\theta_N = 20^\circ$

FIGURE 3-75. CONTINUED.



(H) EFFECT OF FLAP ANGLE. . . AR-8 NOZZLE; $\theta_N = 20^\circ$. .

FIGURE 3-75. CONCLUDED.

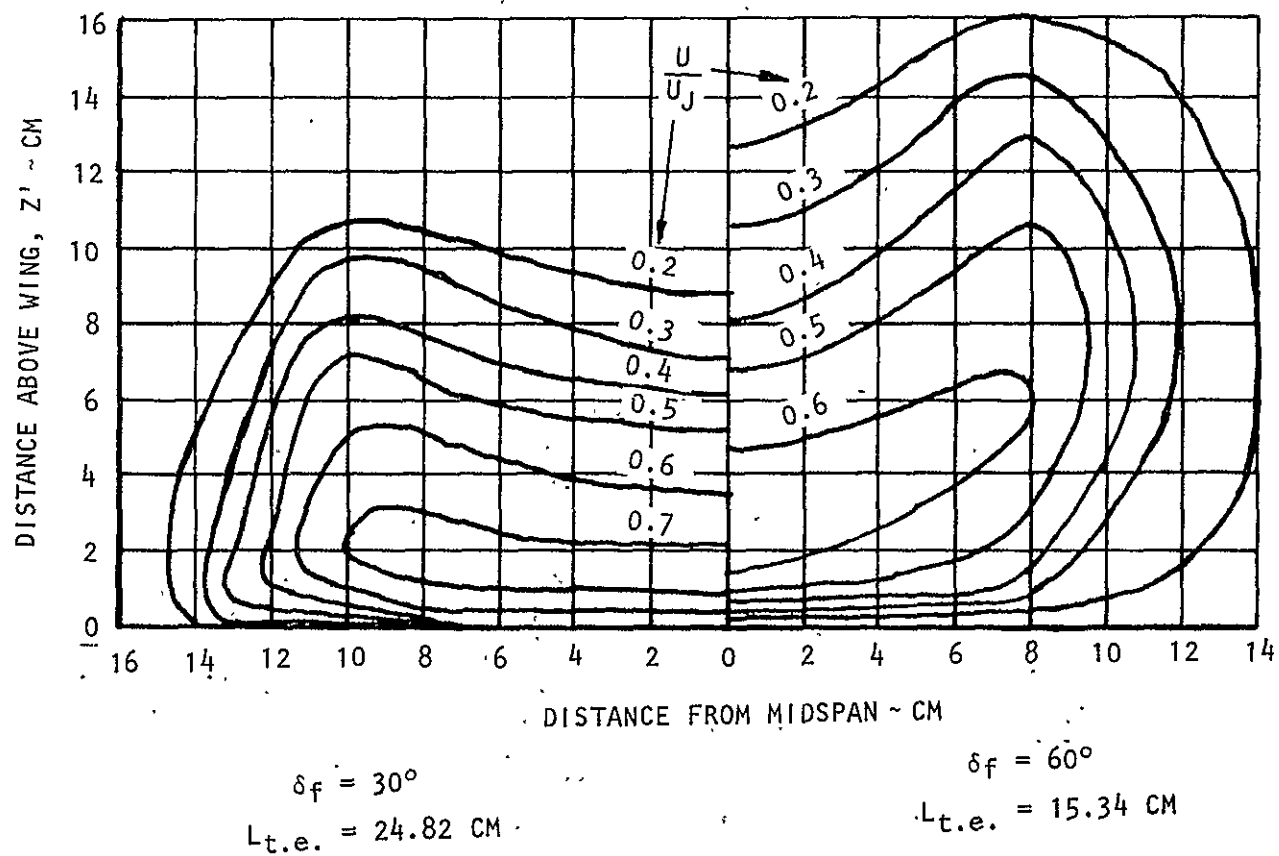
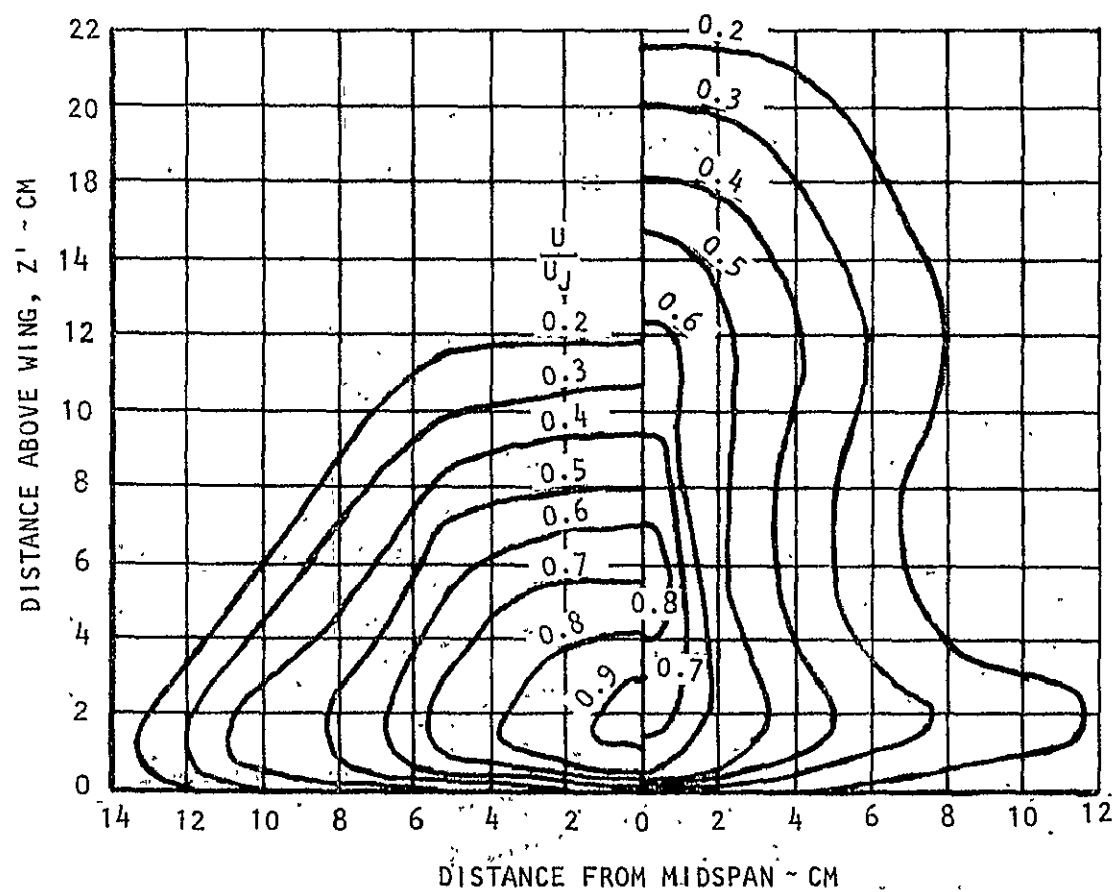


FIGURE 3-76. EFFECT OF FLAP DEFLECTION ON T.E. ISOTACHS; $X_N = 0.20$;
 $\theta_N = 20^\circ$; $NPR = 1.3$; $R_C = 18.06 \text{ CM}$
 (A) AR-8 NOZZLE; $3.79 \times 30.23 \text{ CM}$



$\delta_f = 30^\circ$
 $L_{t.e.} = 24.82 \text{ CM}$

$\delta_f = 60^\circ$
 $L_{t.e.} = 24.82 \text{ CM}$

FIGURE 3-76 (CONTINUED)

(B) AR-4 NOZZLE; $5.33 \times 21.33 \text{ CM}$

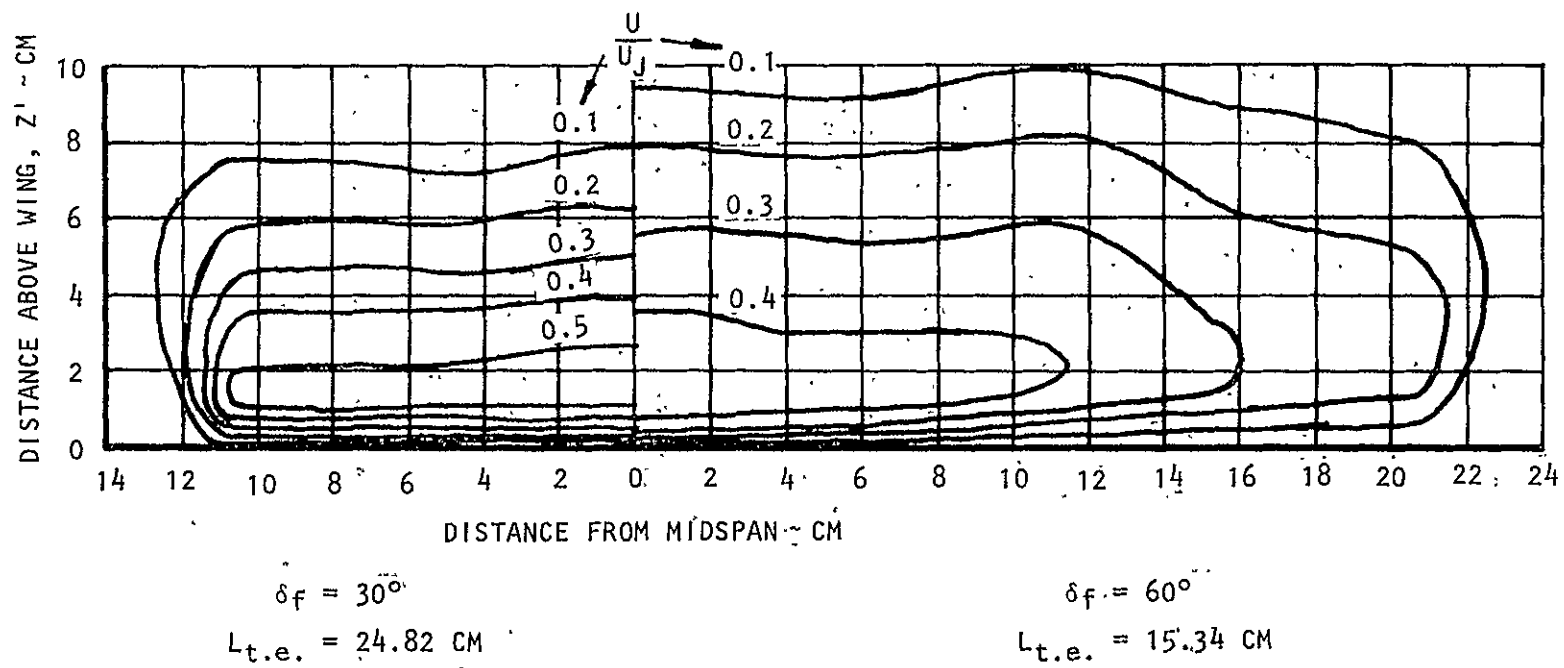


FIGURE 3-76. (CONCLUDED)

(C) AR-4D NOZZLE; $5.33 \times 21.33 \text{ CM}$; $\theta_N = 14^\circ$; $\theta_D = 12^\circ$

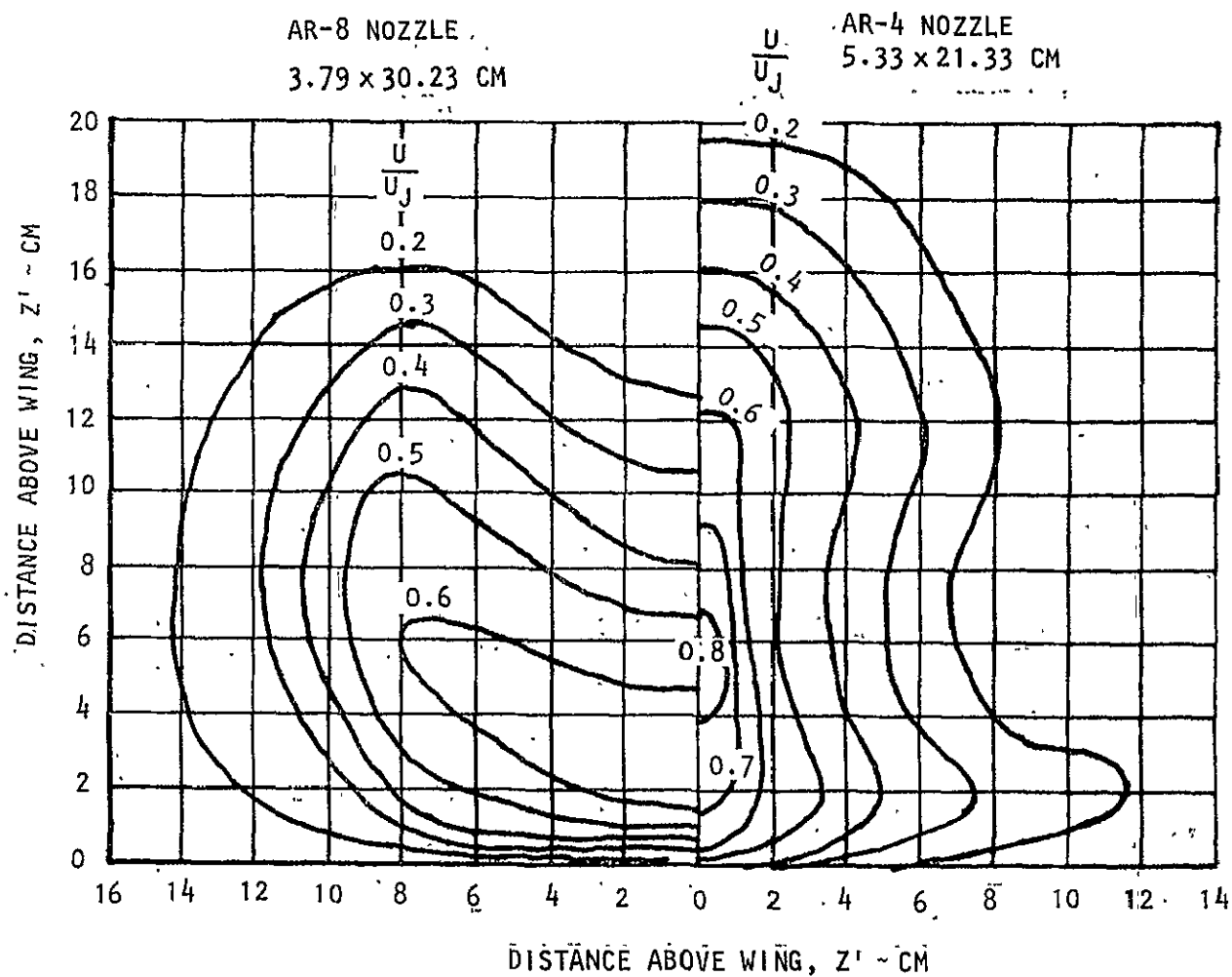


FIGURE 3-77. EFFECT OF NOZZLE ASPECT RATIO ON T.E. ISOTACHS;
 $X_N = 0.2C$; $\theta_N = 20^\circ$; $NPR = 1.3$; $R_C = 18.06$ CM; $\delta_f = 60^\circ$
 (A) $NPR = 1.3$

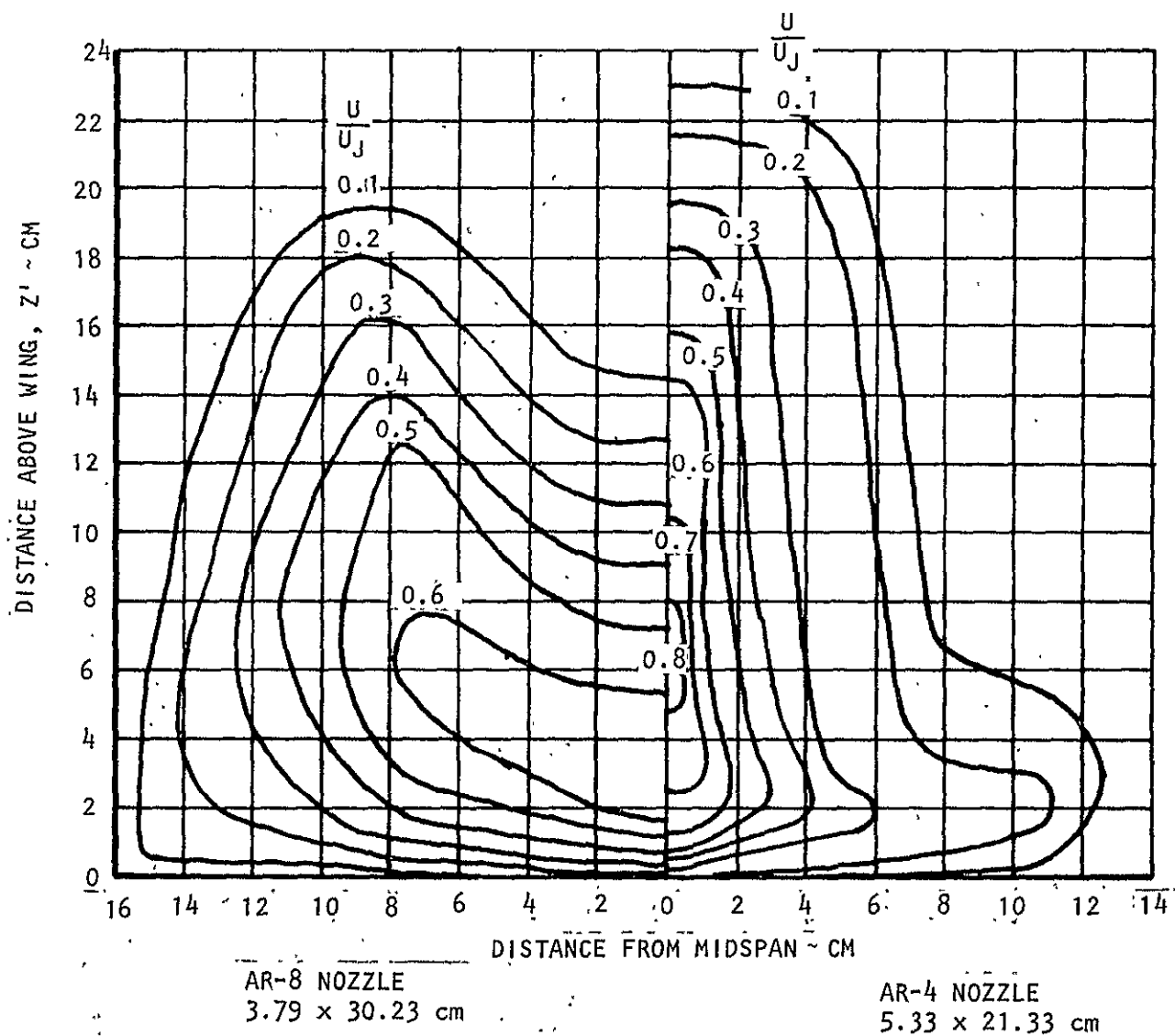


FIGURE 3-77. CONCLUDED.
(B) NPR = 1.6

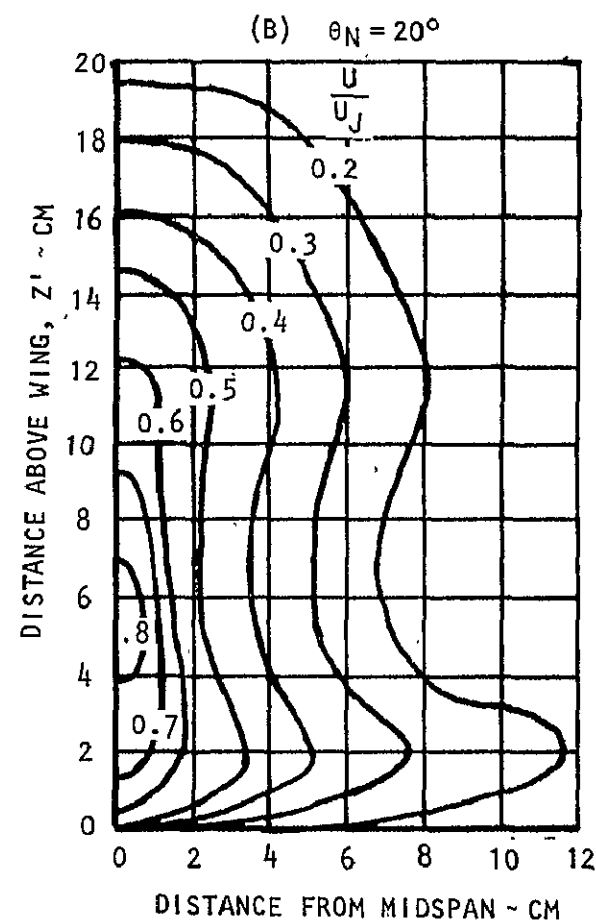
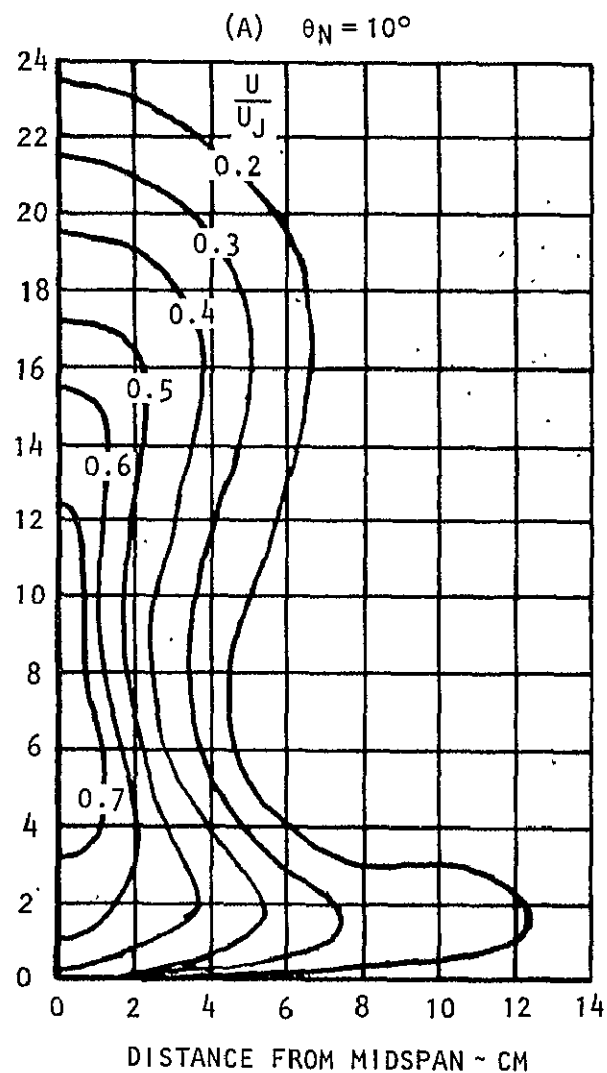


FIGURE 3-78. EFFECT OF IMPINGEMENT ANGLE ON T.E. ISOTACHS;
AR-4 NOZZLE; $5.33 \times 21.33 \text{ CM}$; $X_N = 0.2 \text{ C}$; $R_C = 18.06 \text{ CM}$; $\delta_f = 60^\circ$

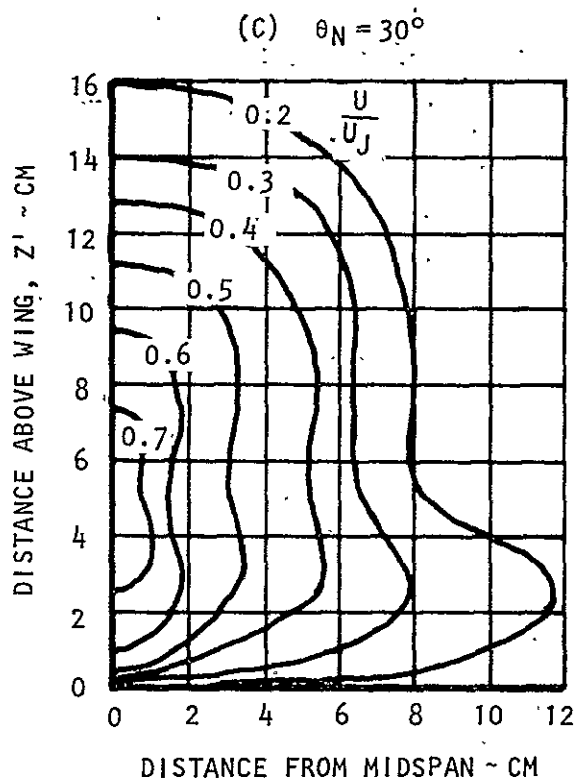


FIGURE 3-78. (CONCLUDED)

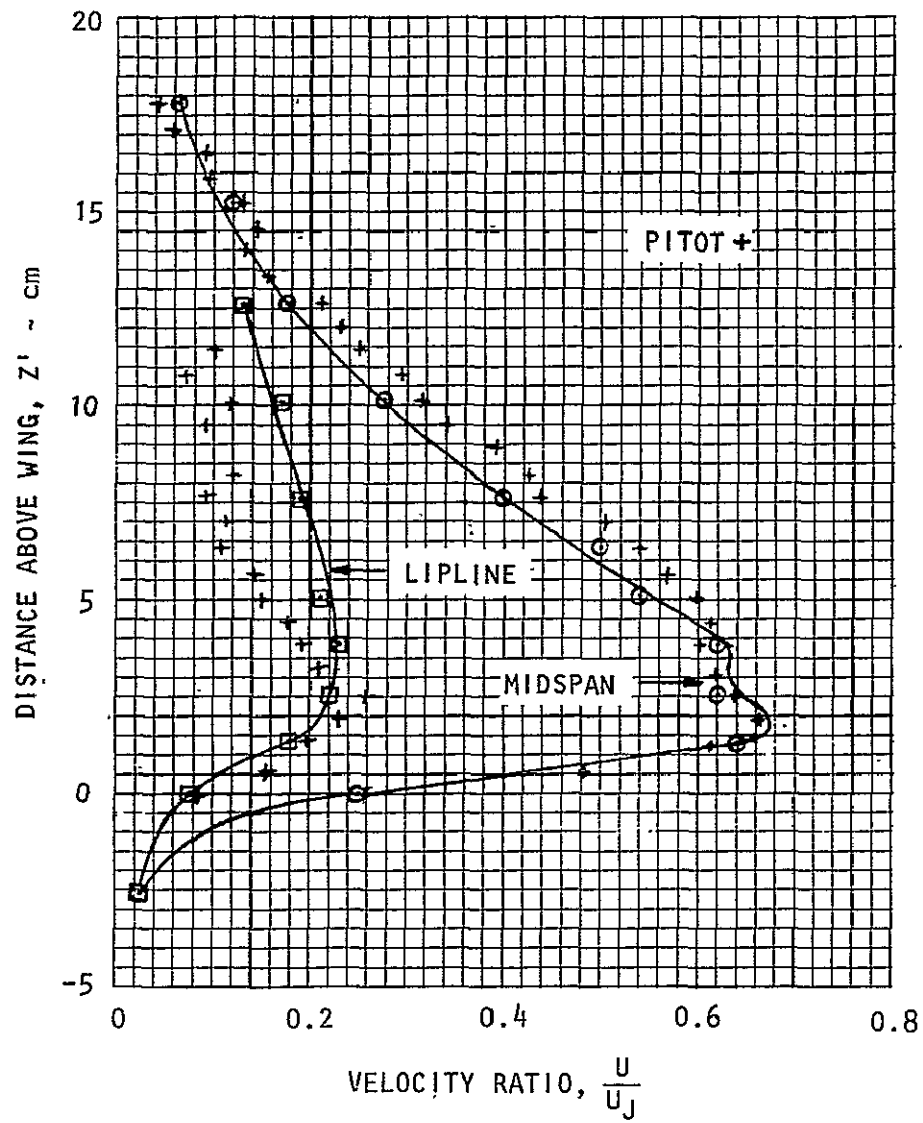


FIGURE 3-79. TRAILING EDGE VELOCITY PROFILES BY HOT-WIRE ANEMOMETRY:
 AR-8 NOZZLE; $X_N = 0.2$ c; $\theta_N = 20^\circ$; $NPR = 1.1$; $R_c = 18.06$ cm;
 $\delta_f = 60^\circ$; $L_{te} = 15.34$ cm
 (A) MEAN VELOCITY

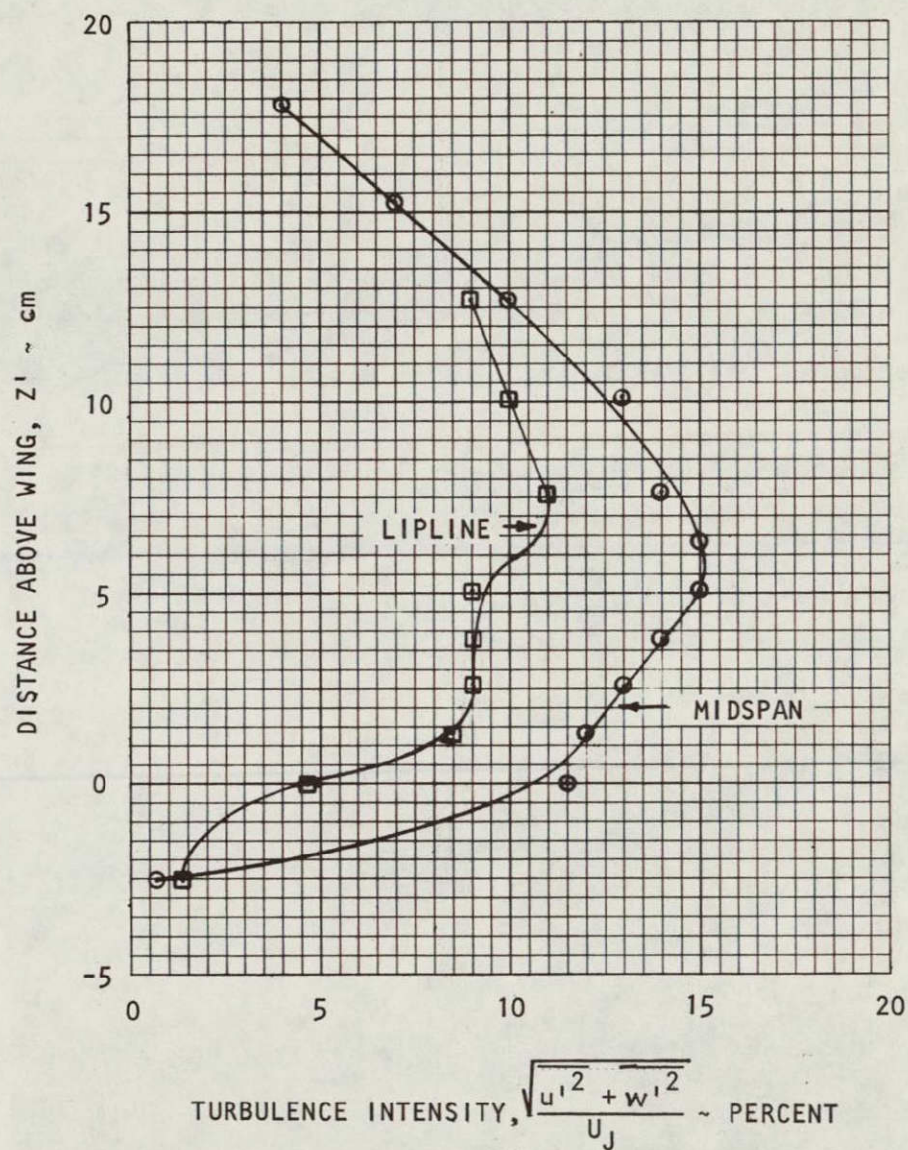
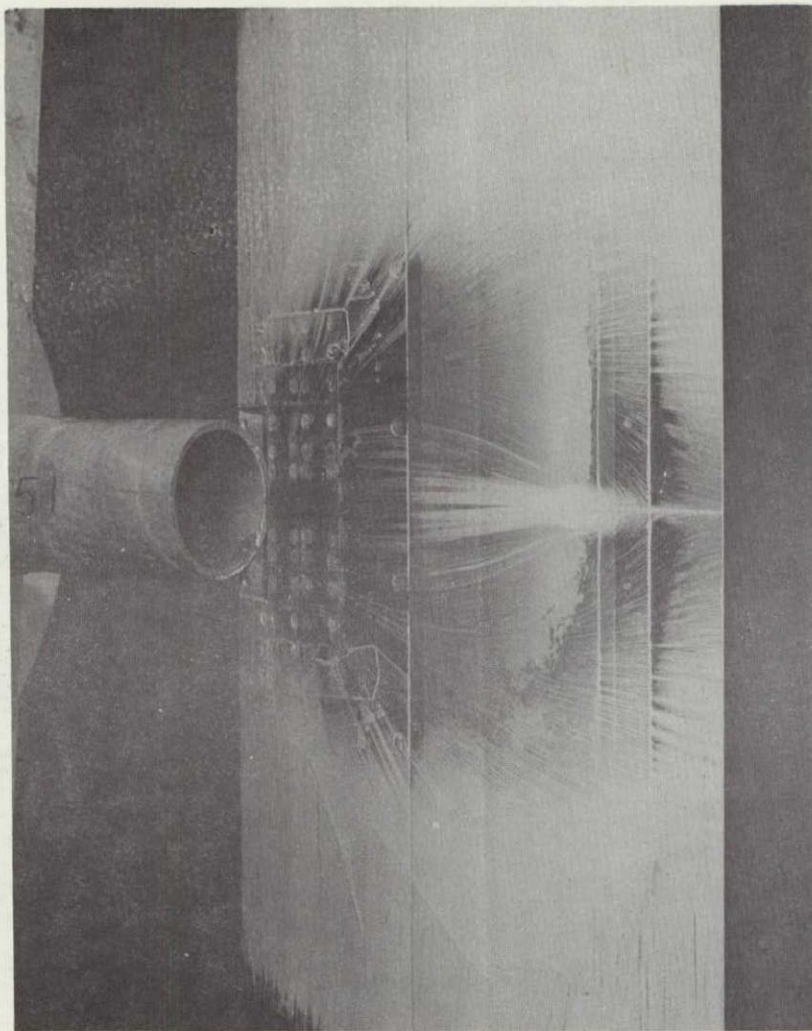


FIGURE 3-79. (CONCLUDED)
(B) TURBULENCE INTENSITY



SMALL SCALE

$$R_c = 7.62 \text{ cm}$$

$$L_{te} = 3.81 \text{ cm}$$

$$\text{NPR} = 1.55$$



LARGE SCALE

$$R_c = 18.06 \text{ cm}$$

$$L_{te} = 15.34 \text{ cm}$$

$$\text{NPR} = 1.44$$

FIGURE 3-80. SURFACE OIL FLOW COMPARISON; CIRCULAR NOZZLE,
 $x_N = 0.2 \text{ c}$, $\theta_N = 20^\circ$, $\delta f = 60^\circ$

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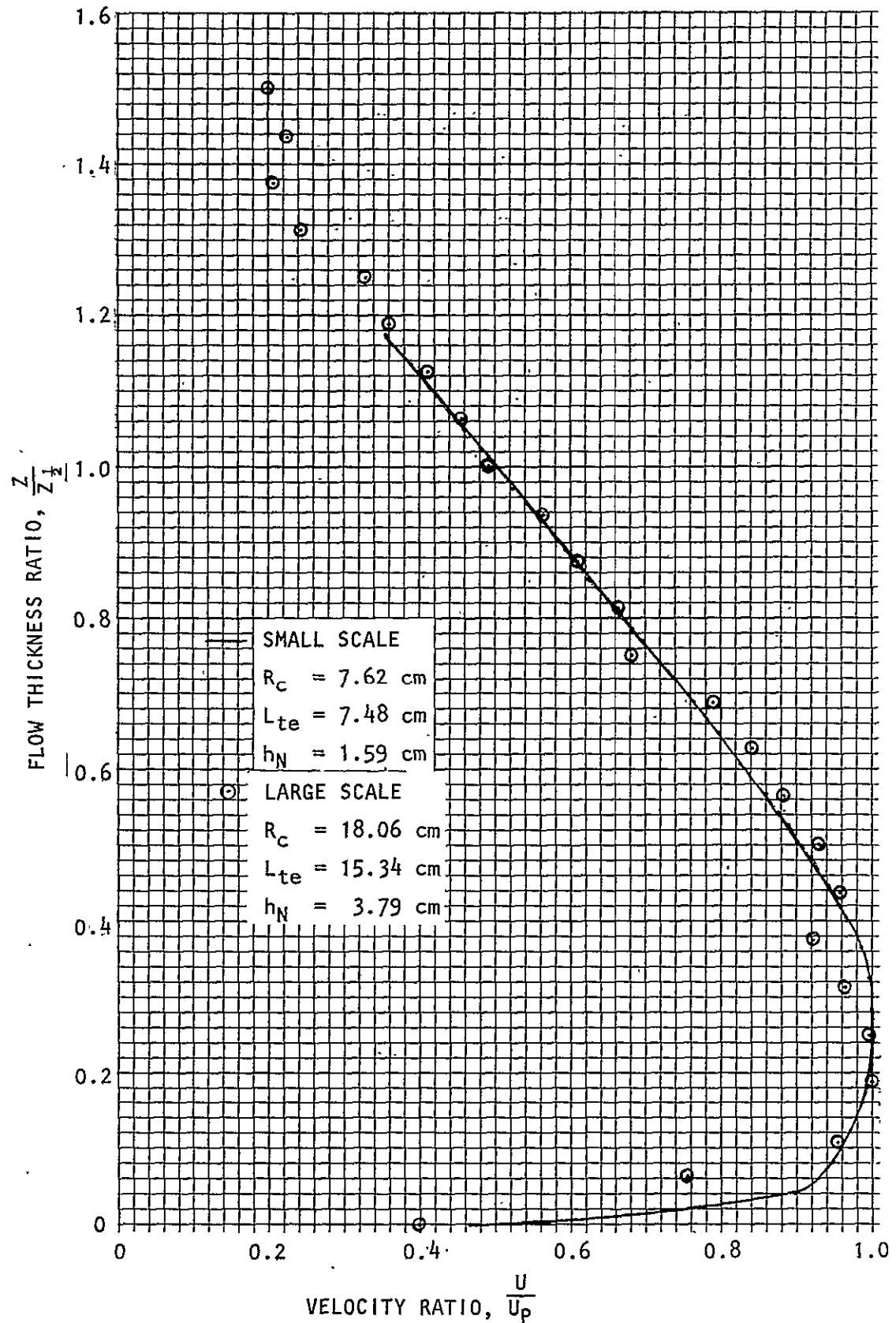


FIGURE 3-81. MIDSPAN VELOCITY PROFILE COMPARISON, NPR = 1.1
(A) AR-8 NOZZLES

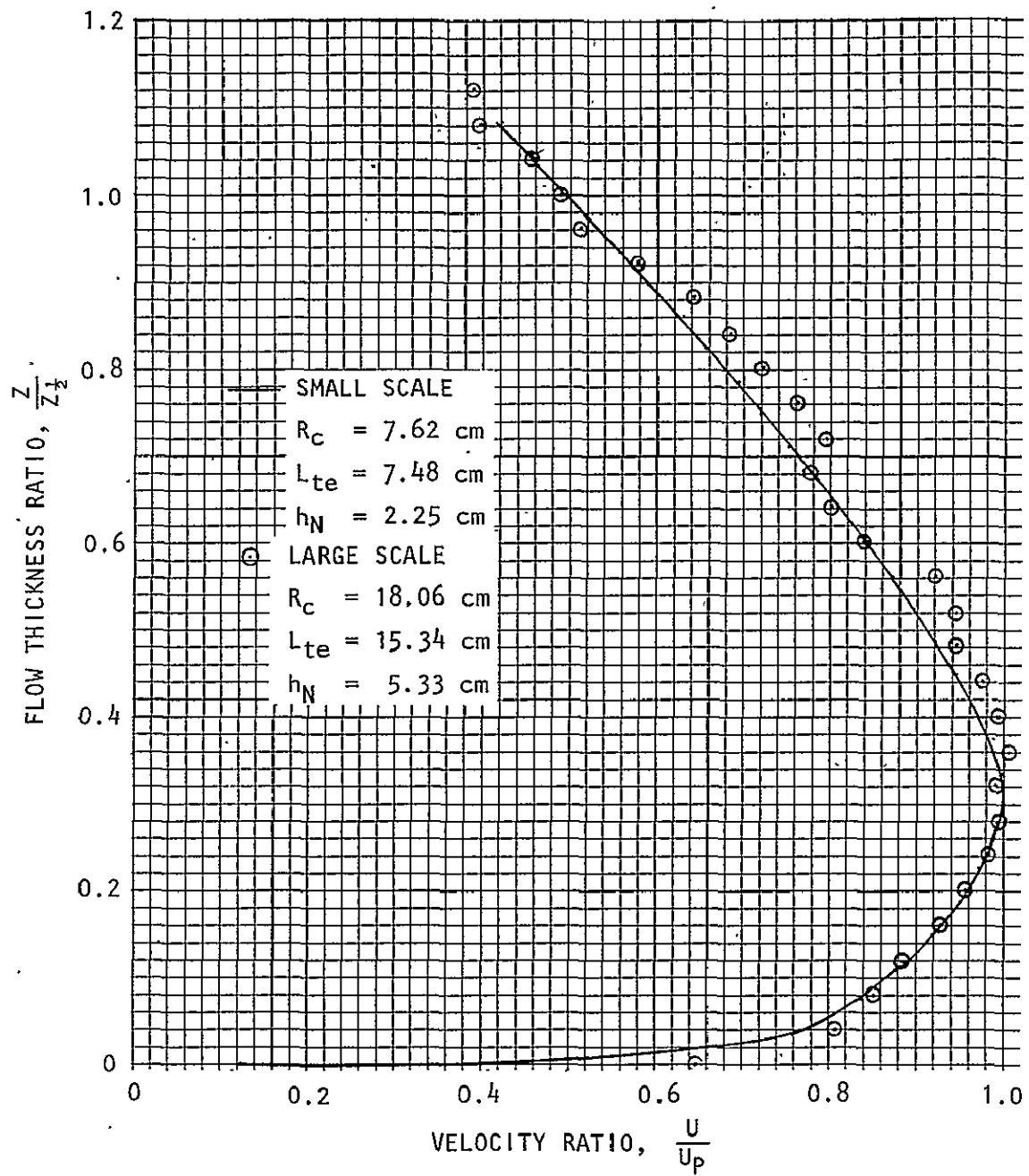


FIGURE 3-81. (CONCLUDED)
 (B) AR-4 NOZZLES

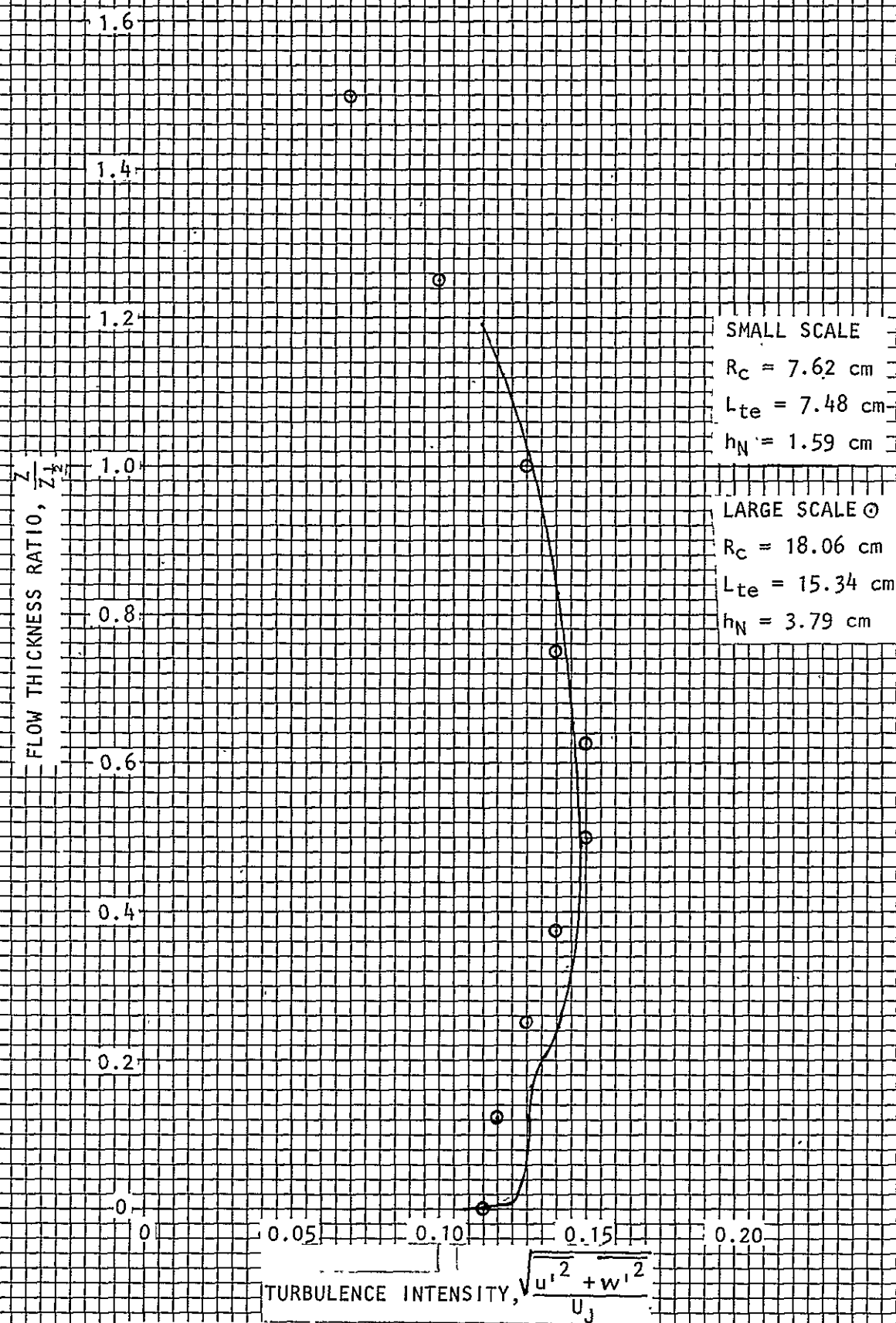


FIGURE 3-82. MIDSPAN TURBULENCE INTENSITY PROFILE COMPARISON;
 AR-8 NOZZLE; $X_N = 0.20 \text{ c}$; $\theta_N = 20^\circ$; $\text{NPR} = 1.1$;
 $\delta_f = 60^\circ$ 3-177.

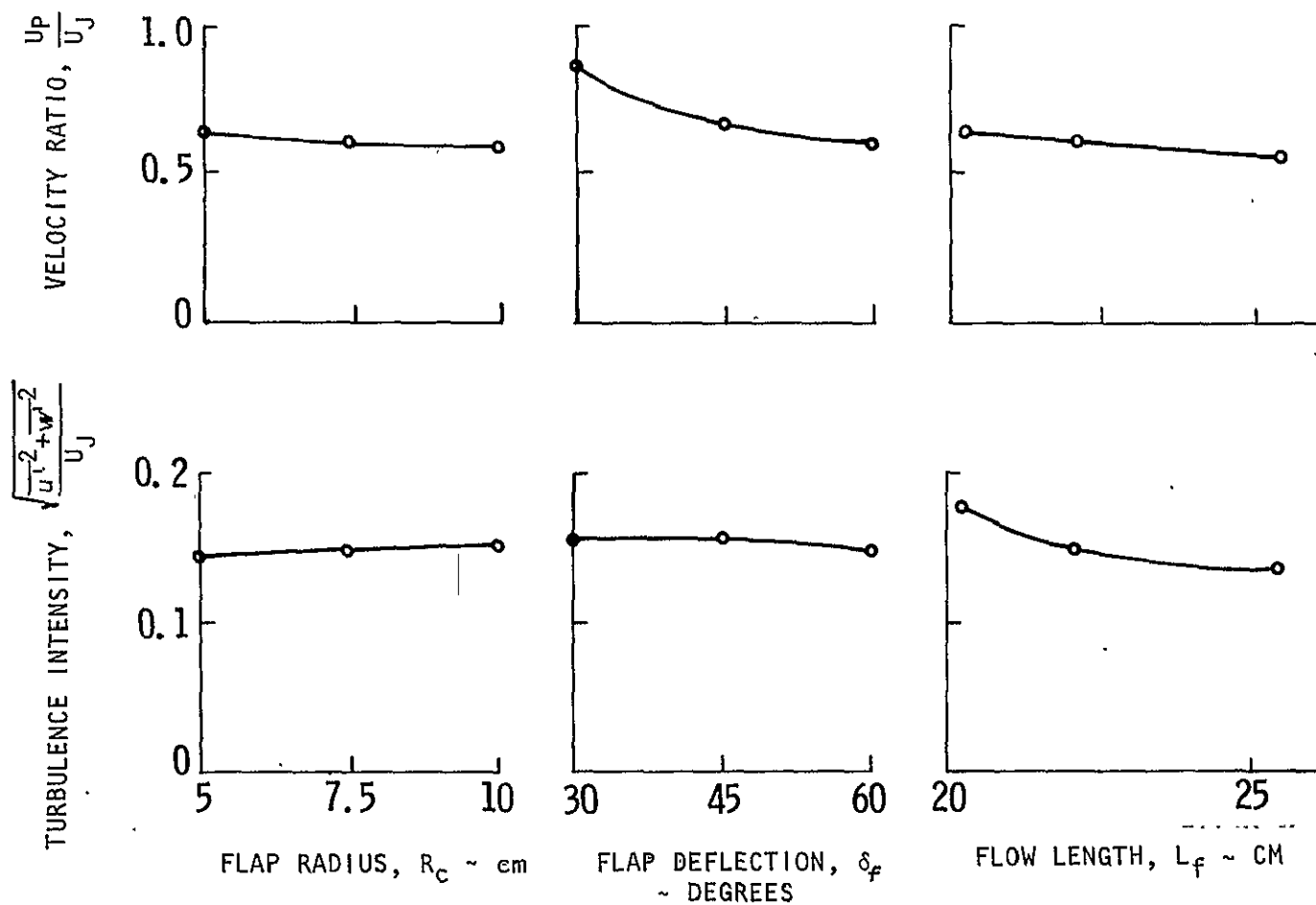


FIGURE 3-83. EFFECTS OF VARIABLES ON PEAK VELOCITY AND TURBULENCE INTENSITY
 (A) EFFECT OF FLAP VARIABLES, $\theta_N = 20^\circ$, $X_N = 0.2C$, $A_N = 20.26 \text{ CM}^2$,
 $L_f = 21.77 \text{ CM}$, $\text{NPR} = 1.1$.

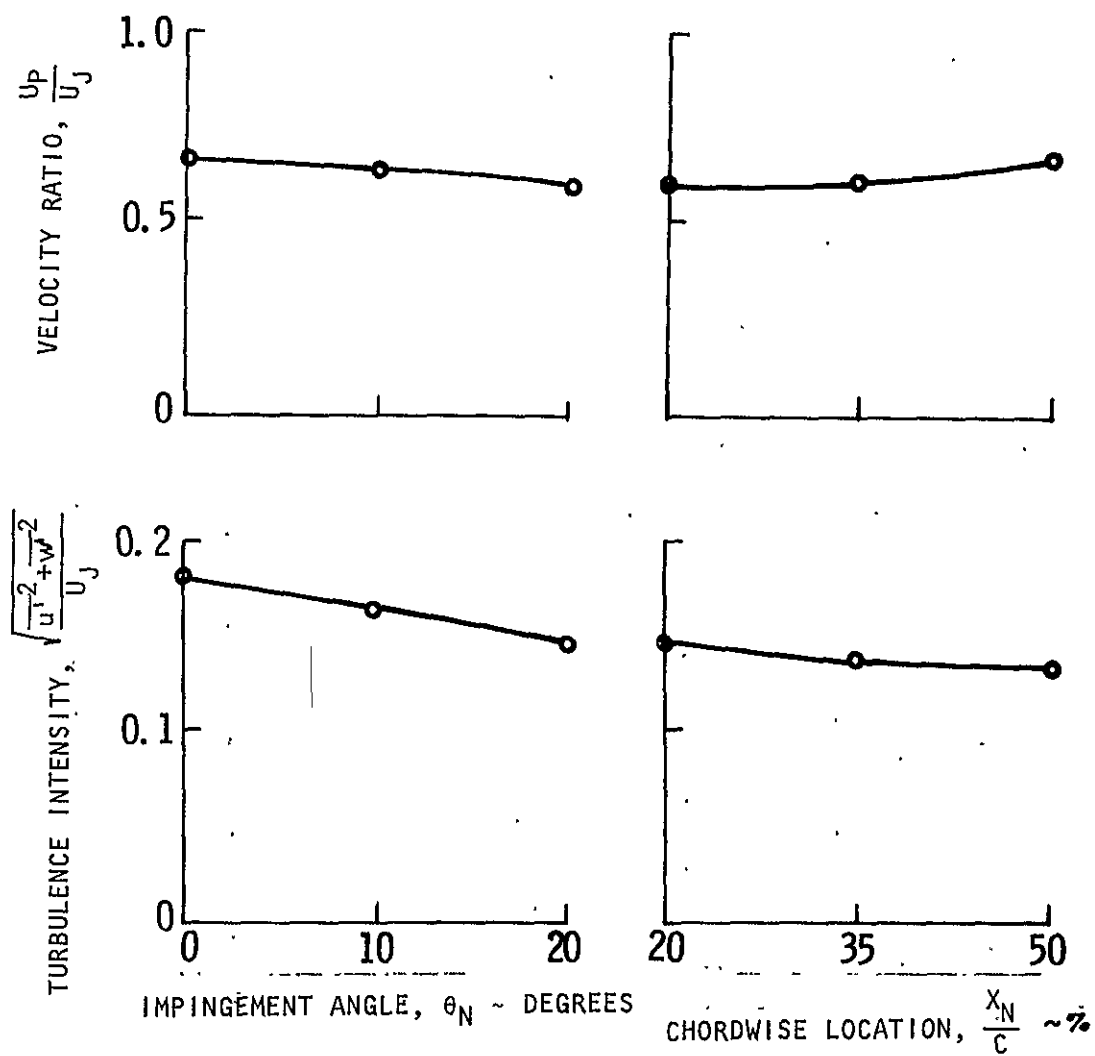
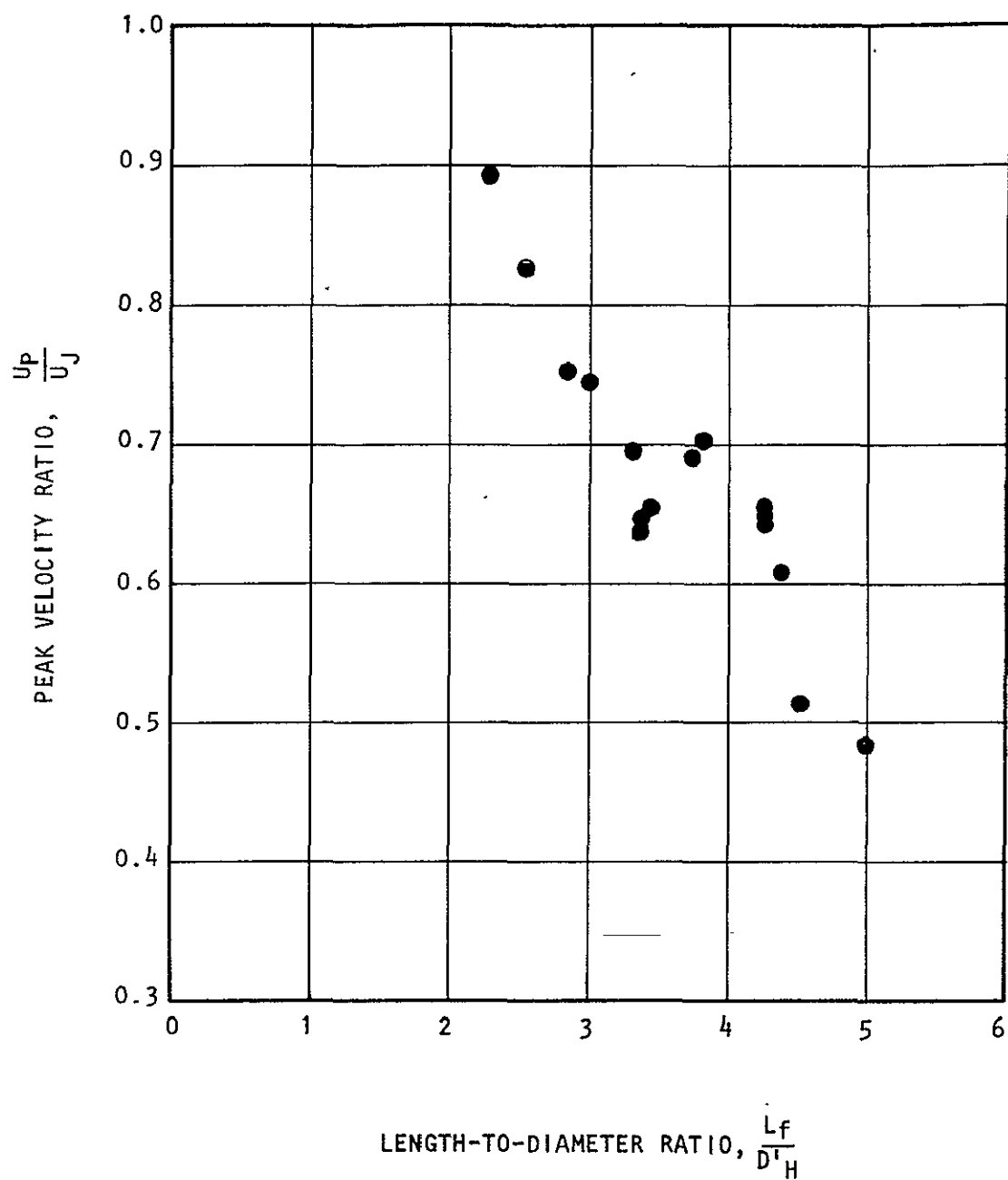


FIGURE 3-83. (CONCLUDED)
 (B) EFFECT OF INSTALLATION VARIABLES
 $R_C = 7.62$ CM, $\delta_f = 60^\circ$



NPR = 1.1-1.6, $X_N = 0.2C$, $\theta_N = 10^\circ-30^\circ$

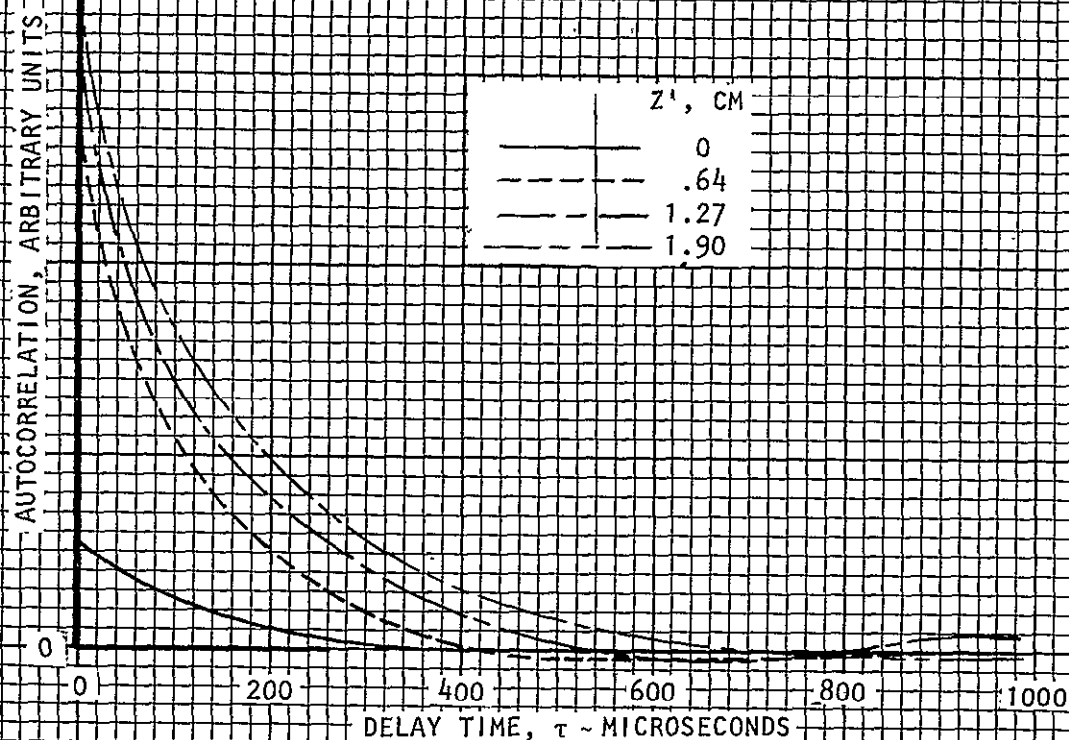
$D_H = 4.5-12.1\text{CM}$, $R_C = 5.08-10.03\text{CM}$, $\delta_f = 30^\circ-60^\circ$

$X' = 0$, $Y = 0$

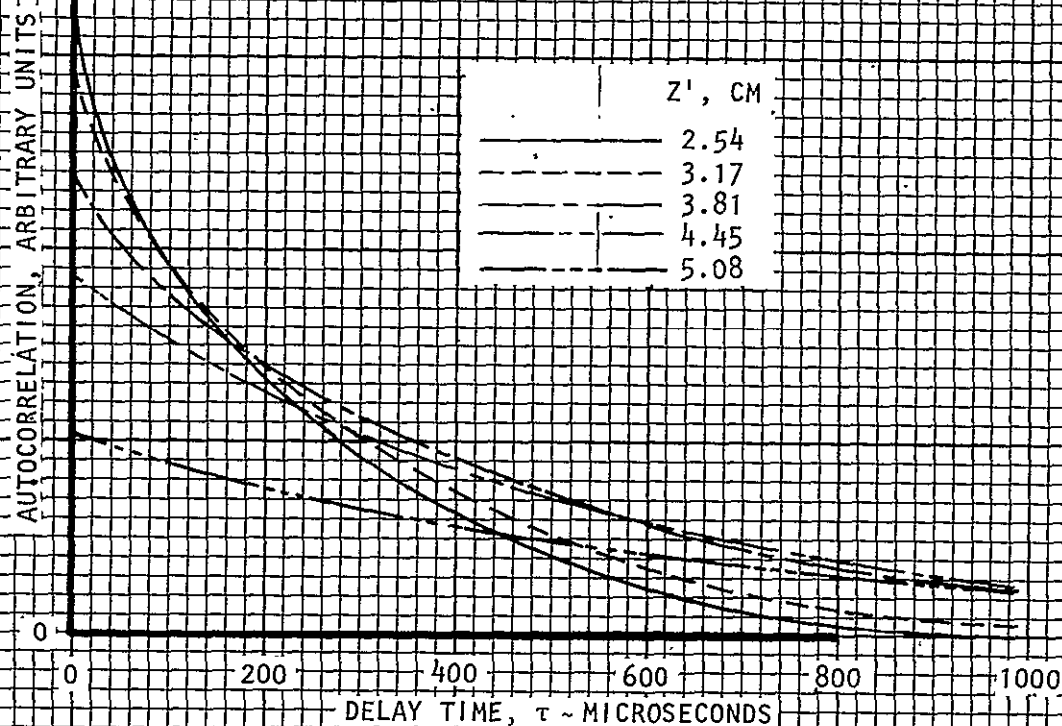
NOTE: DATA CORRECTED TO $\delta_f = 60^\circ$, $\theta_N = 20^\circ$, AND $L_f/R_C = 2.86$.

FIGURE 3-84. SUMMARY OF PEAK VELOCITY DATA

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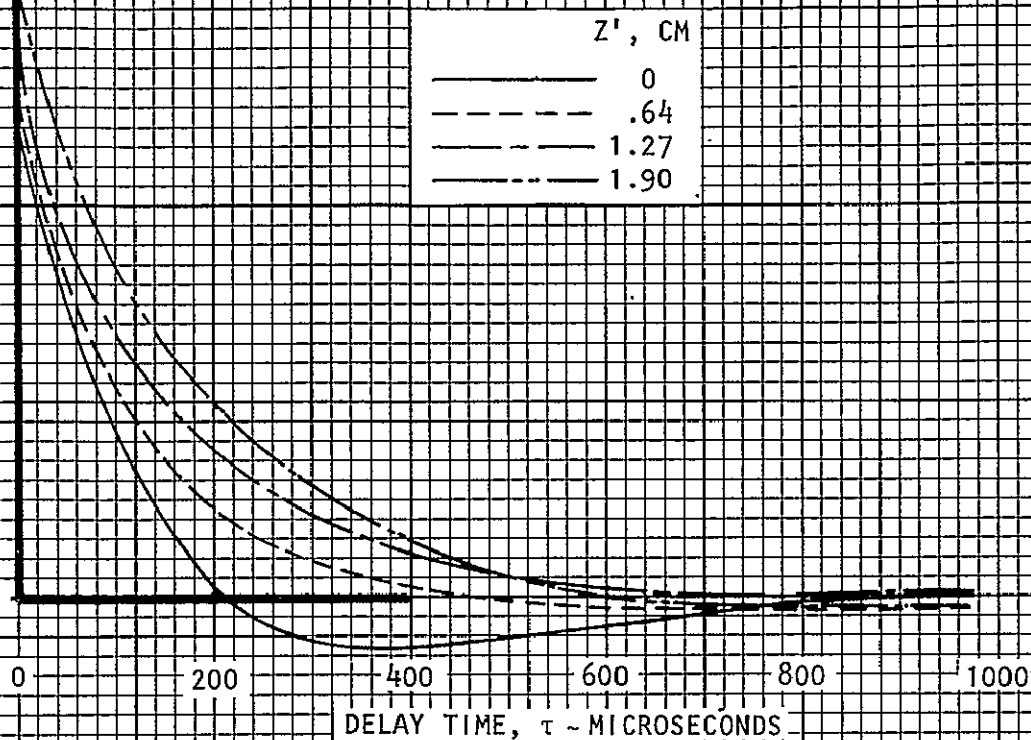
(A) $X' = .20$ CM; $Z' = 0 - 1.90$ CM.



(B) $X' = .20$ CM; $Z' = 2.54 - 5.08$ CM.

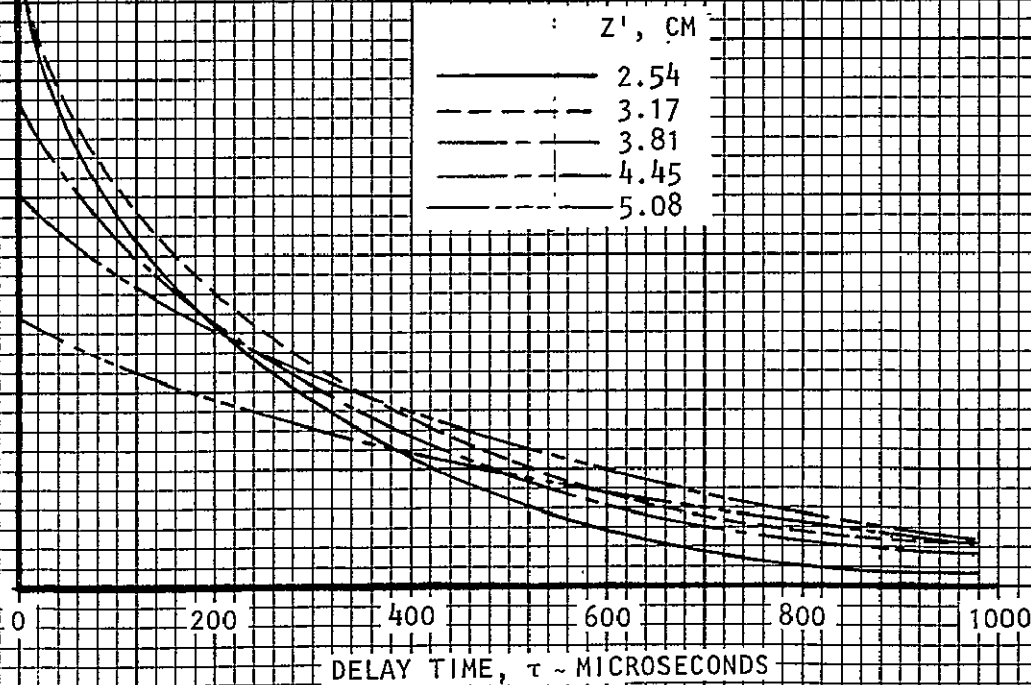
FIGURE 3-85'. AUTOCORRELATIONS OF $\sqrt{u'^2 + w'^2}$ AT TRAILING EDGE.
AR-8 NOZZLE; $X_N = .20C$; $\theta_N = 20^\circ$; $R_C = 5.08$ CM;
 $\theta_f = 60^\circ$; $L_{te} = 3.81$ CM; $NPR = 1.1$.

AUTOCORRELATION, ARBITRARY UNITS



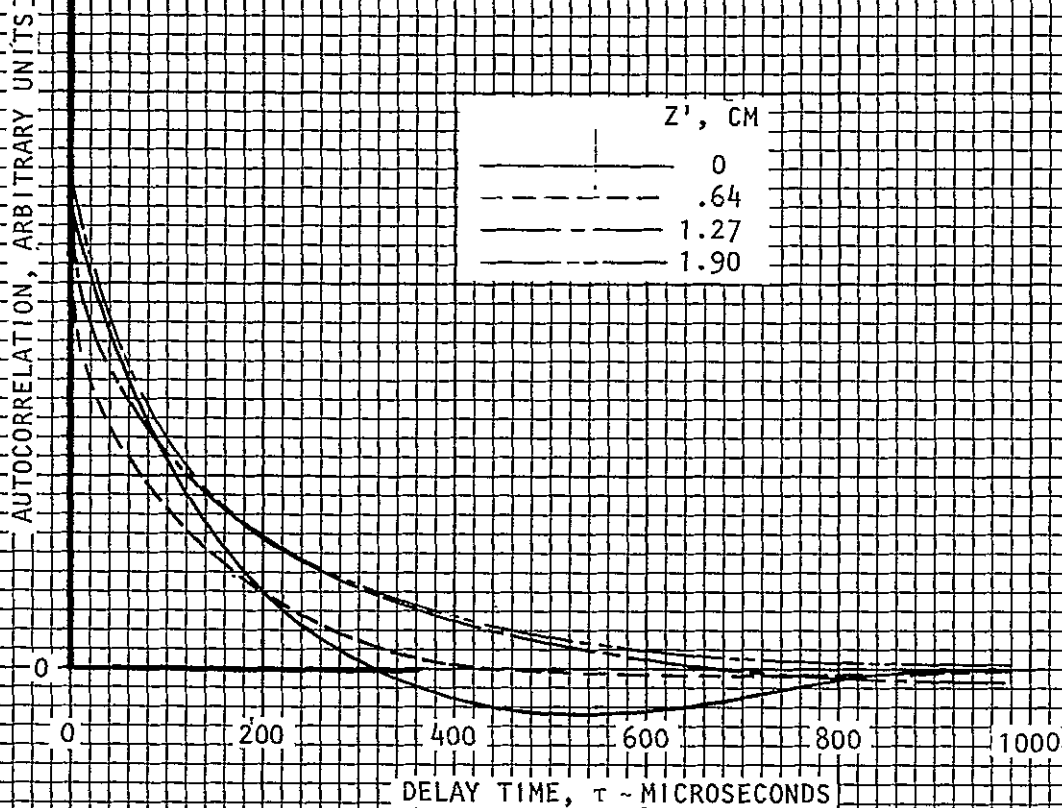
(C) $X' = 1.27$ CM; $Z' = 0 - 1.90$ CM.

AUTOCORRELATION, ARBITRARY UNITS

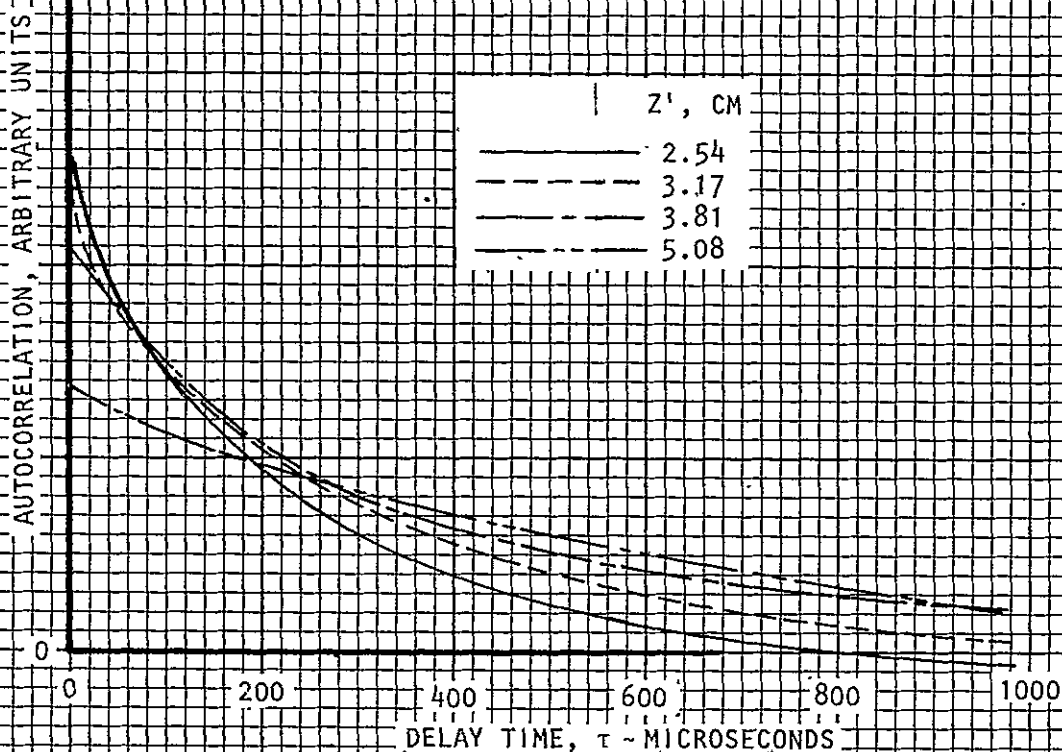


(D) $X' = 1.27$ CM; $Z' = 2.54 - 5.08$ CM.

FIGURE 3-85. CONTINUED.



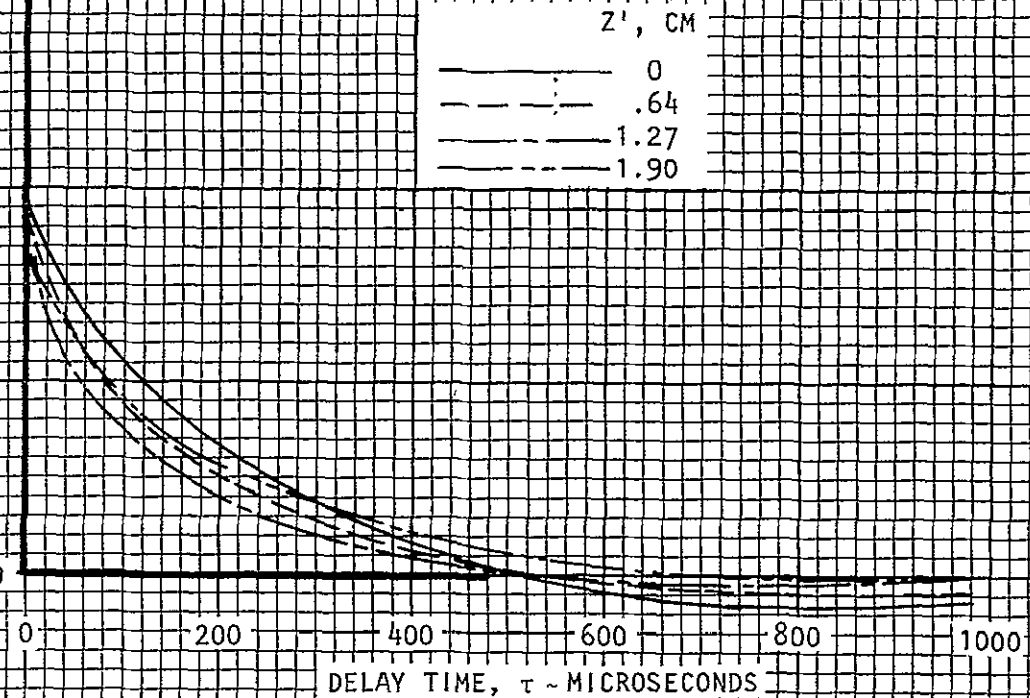
(E) $X' = 2.54$ CM; $Z' = 0 - 1.90$ CM.



(F) $X' = 2.54$ CM; $Z' = 2.54 - 5.08$ CM.

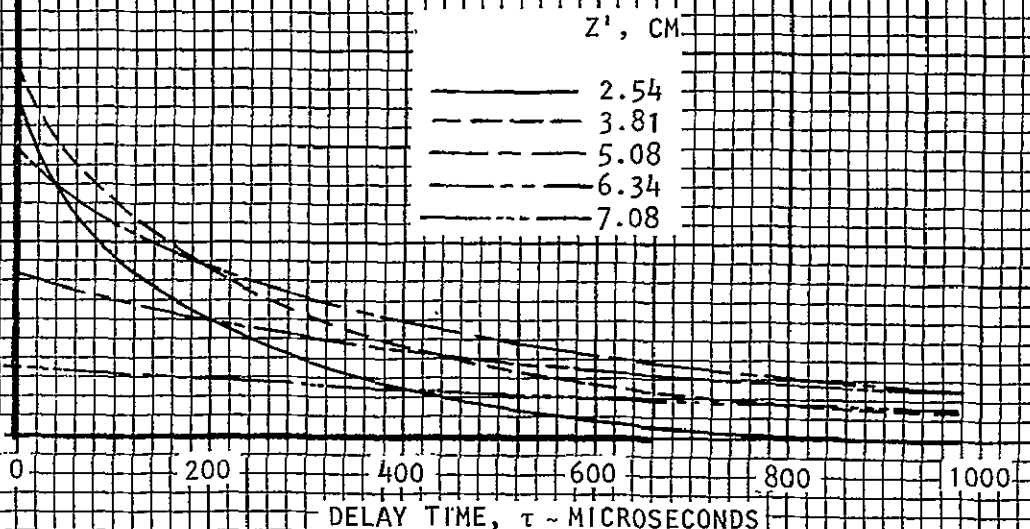
FIGURE 3-85. CONTINUED.

AUTOCORRELATION, ARBITRARY UNITS



(G) $X' = 5.08$ CM; $Z' = 0 - 1.90$ CM.

AUTOCORRELATION, ARBITRARY UNITS



(H) $X' = 5.08$ CM; $Z' = 2.54 - 7.62$ CM.

FIGURE 3-85. CONCLUDED.

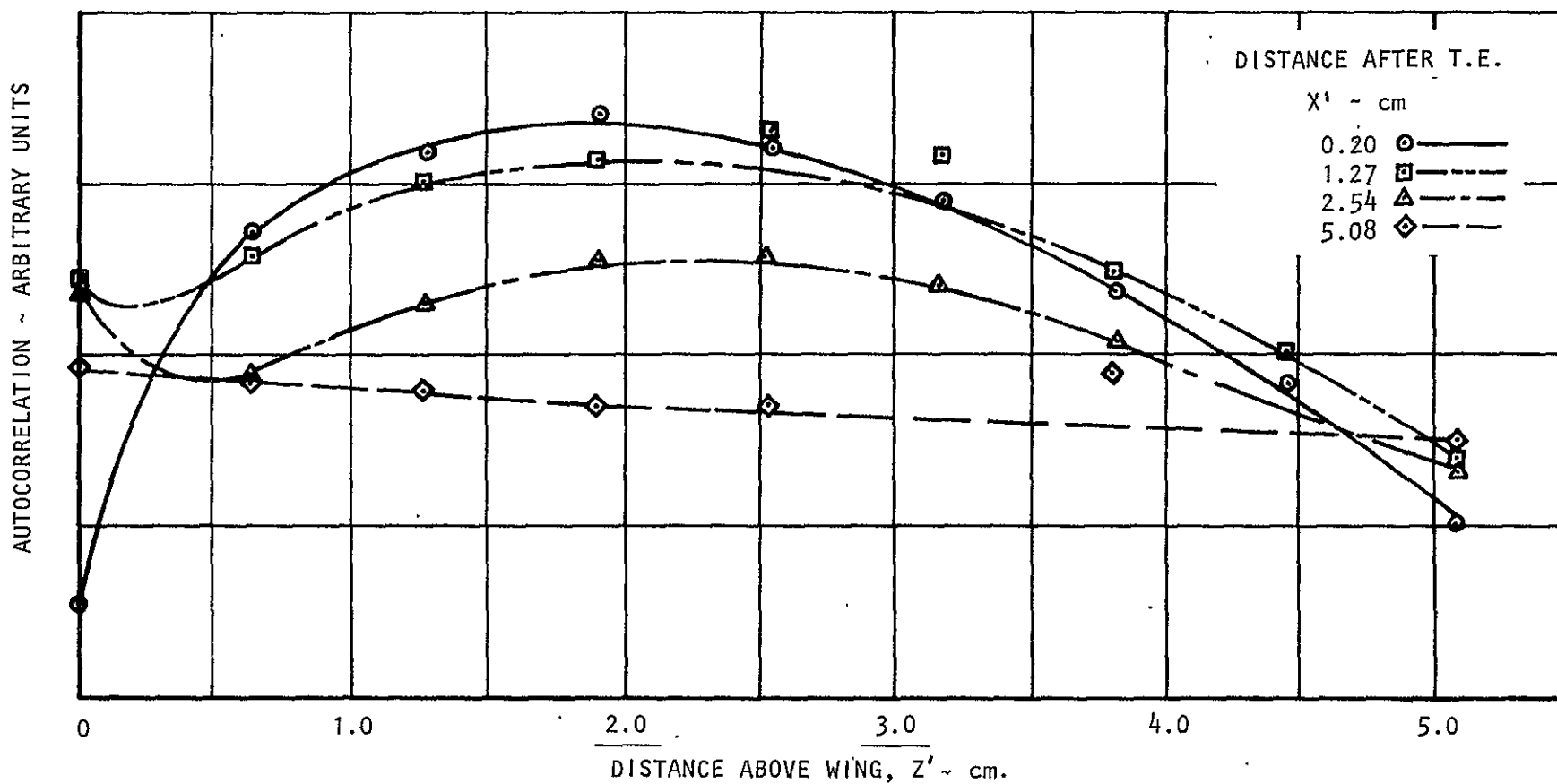


FIGURE 3-86. PEAK AUTOCORRELATION DISTRIBUTION IN THE WAKE;
 AR-8 NOZZLE; 12.73×1.59 cm; $X_N = 0.20$ c;
 $\theta_N = 20^\circ$; NPR = 1.1; $R_c = 5.08$ cm; $\delta_f = 60^\circ$;
 $L_{te} = 3.81$ cm.

SPACE/TIME CORRELATION ~ ARBITRARY UNITS

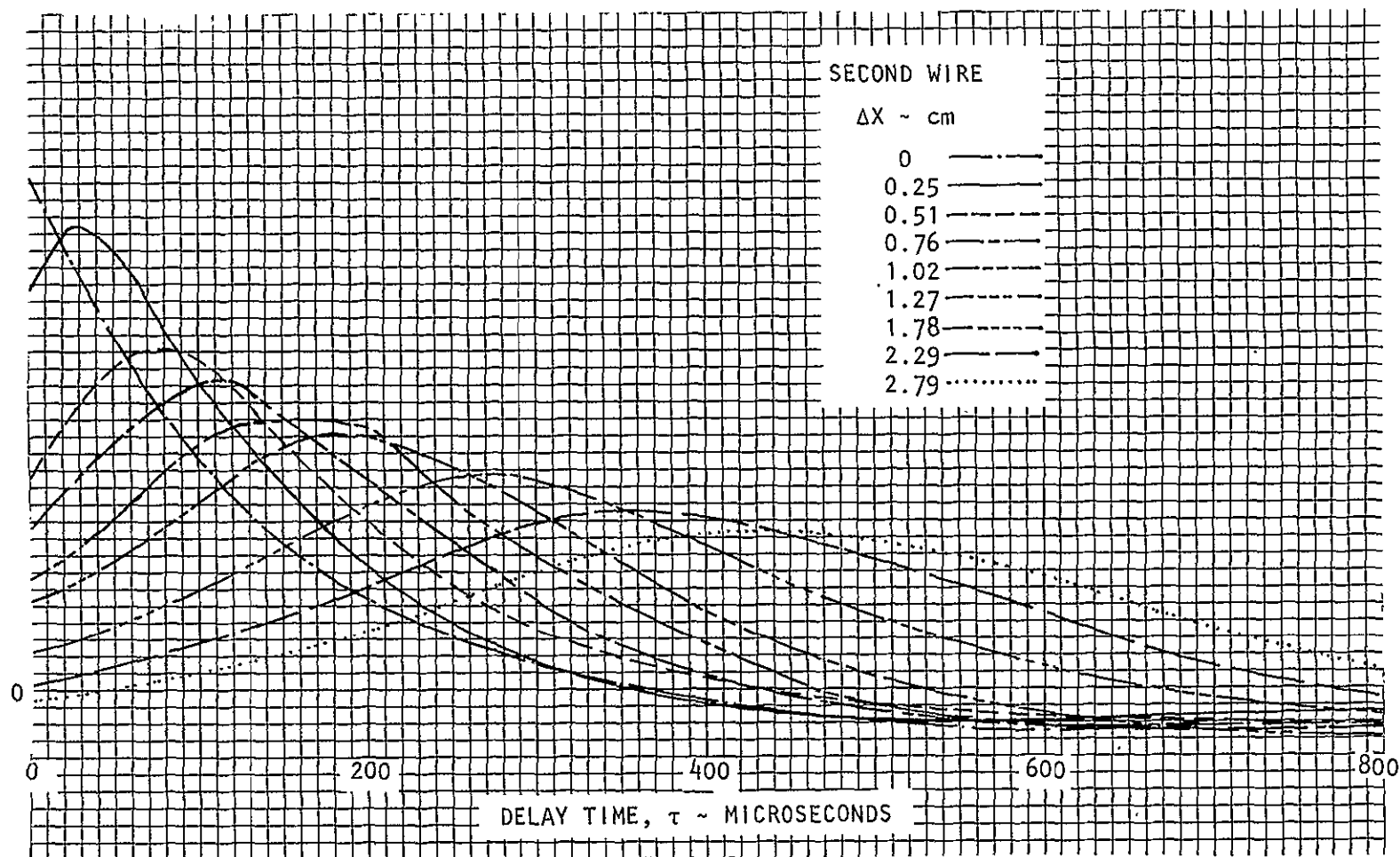


FIGURE 3-87.. STREAMWISE SPACE/TIME CORRELATIONS OF $\sqrt{u'^2 + w'^2}$ IN THE WAKE;
 AR-8 NOZZLE; $12.73 \times 1.59 \text{ cm}$; $X_N = 0.20 \text{ c}$; $\theta_N = 20^\circ$; $\text{NPR} = 1.1$;
 $R_c = 7.62 \text{ cm}$; $\delta_f = 60^\circ$; $L_{te} = 6.47 \text{ cm}$; $Y = 0$; $Z' = 0.1 \text{ cm}$;
 (A) $X'_1 = 0.76 \text{ cm}$

SPACE/TIME CORRELATION ~ ARBITRARY UNITS

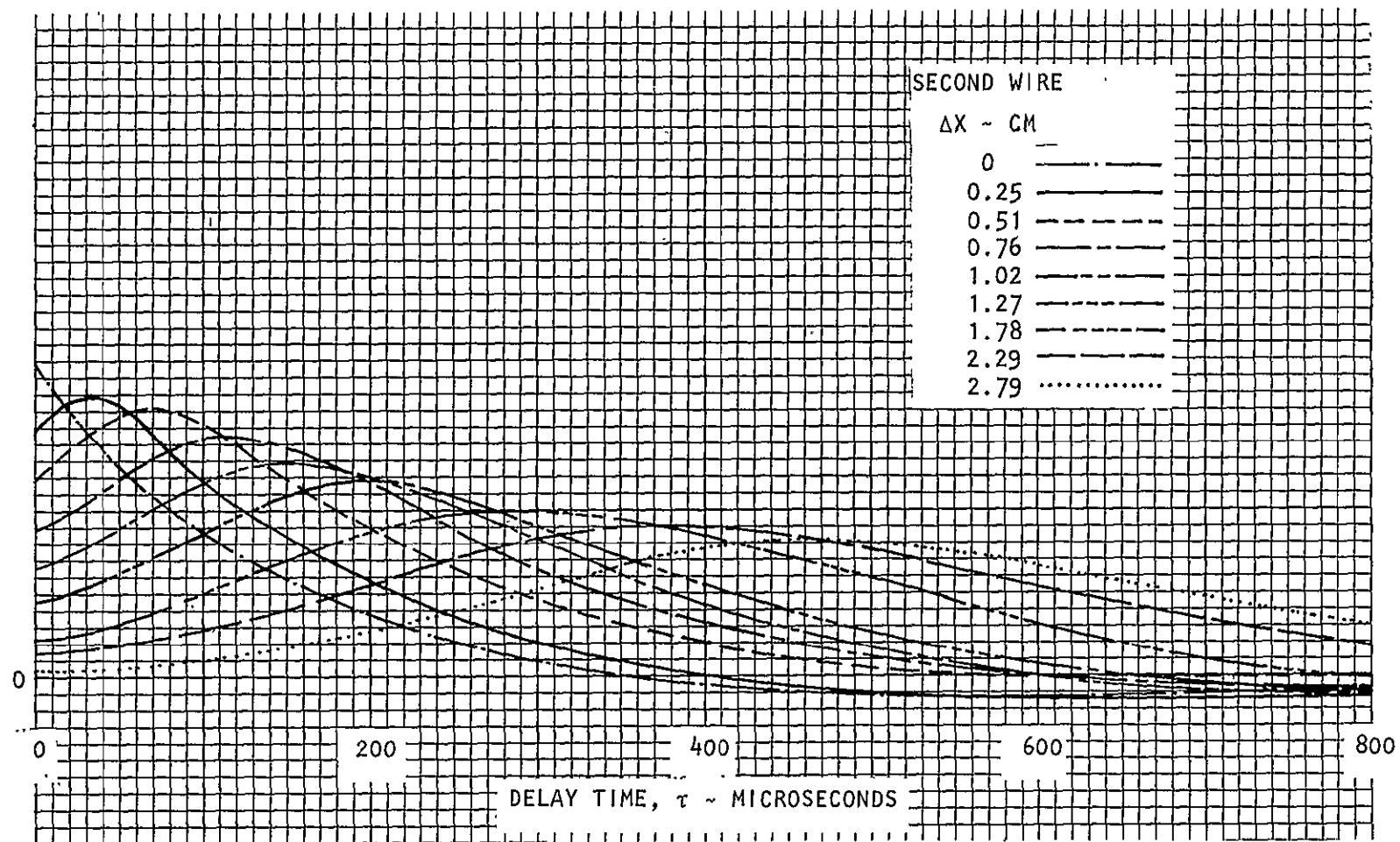


FIGURE 3-87 (CONTINUED)
 (B) $X_1' = 1.59$ cm

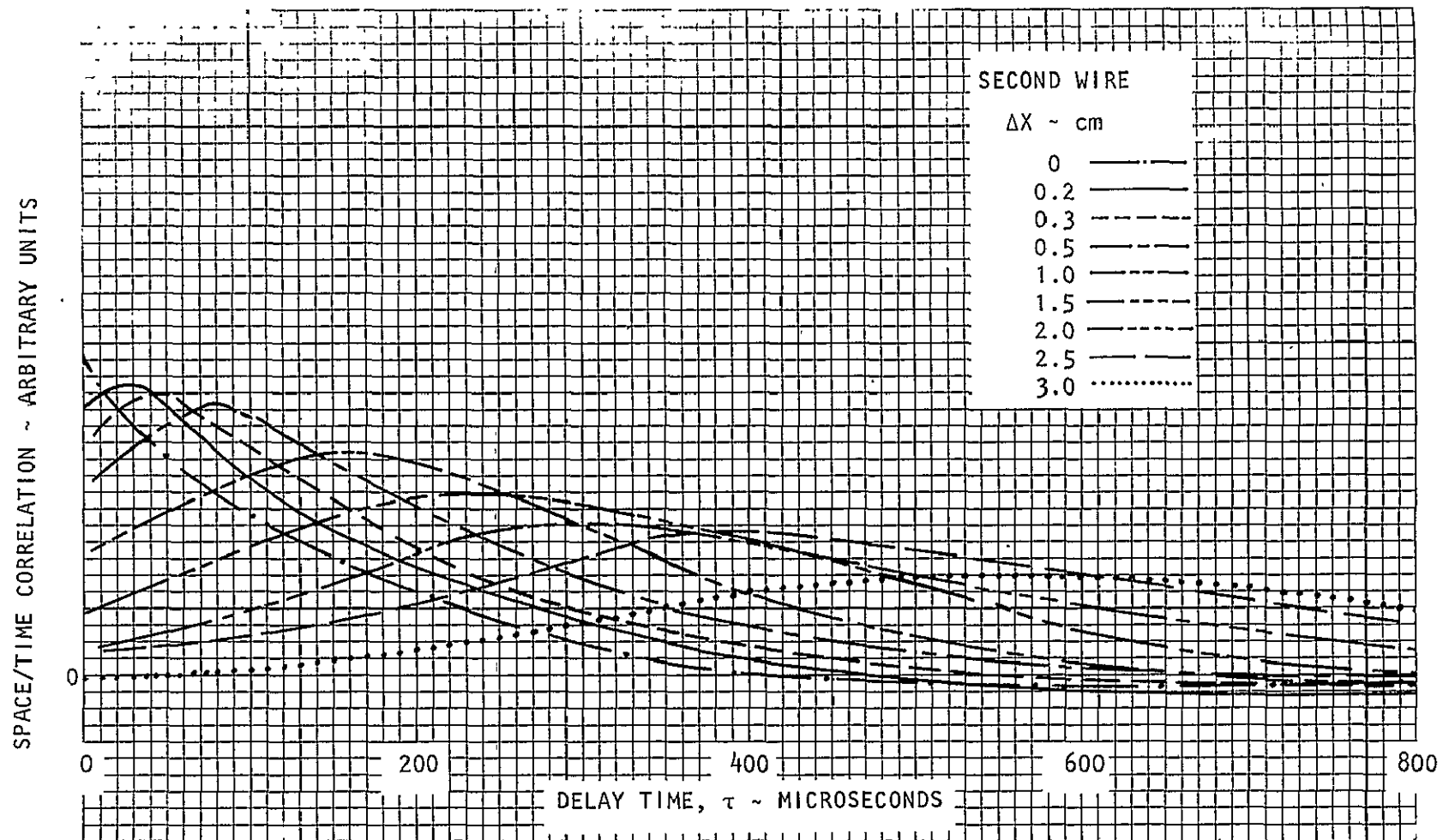


FIGURE 3-87 (CONCLUDED)
 (C) $X_1' = 2.54 \text{ cm}$

SPACE/TIME CORRELATION ~ ARBITRARY UNITS

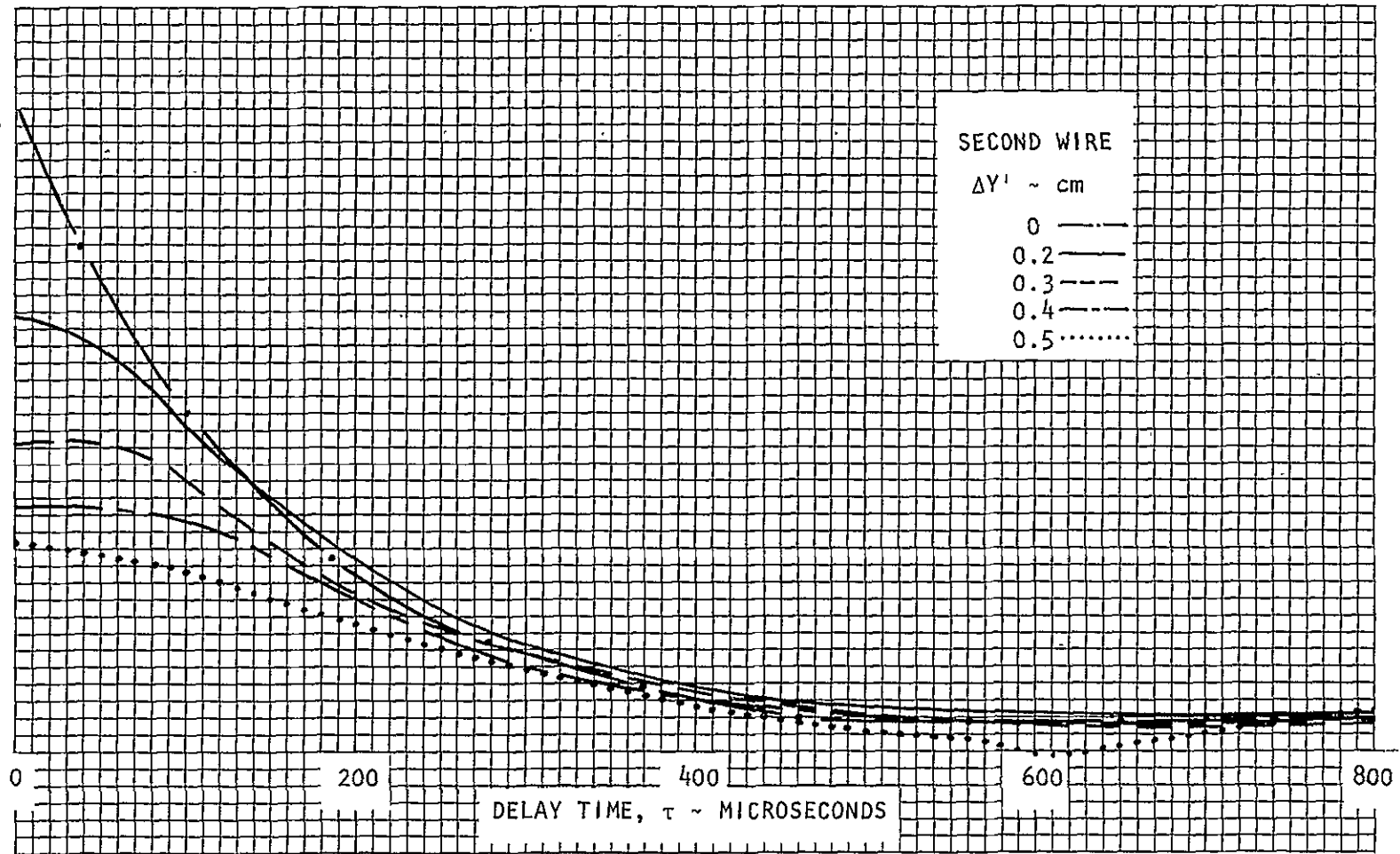


FIGURE 3-88. LATERAL SPACE/TIME CORRELATIONS OF $\sqrt{u'^2 + w'^2}$ IN THE WAKE;
 AR-8 NOZZLE; 12.73×1.59 cm; $X_N = 0.2$ c; $\theta_N = 20^\circ$; $NPR = 1.1$;
 $R_c = 7.62$ cm; $\delta_f = 60^\circ$; $L_{te} = 6.47$ cm, $X' = 1.59$ cm; $Y'_1 = 0$;
 $Z' = 0.1$ cm.

SPACE/TIME CORRELATION ~ ARBITRARY UNITS

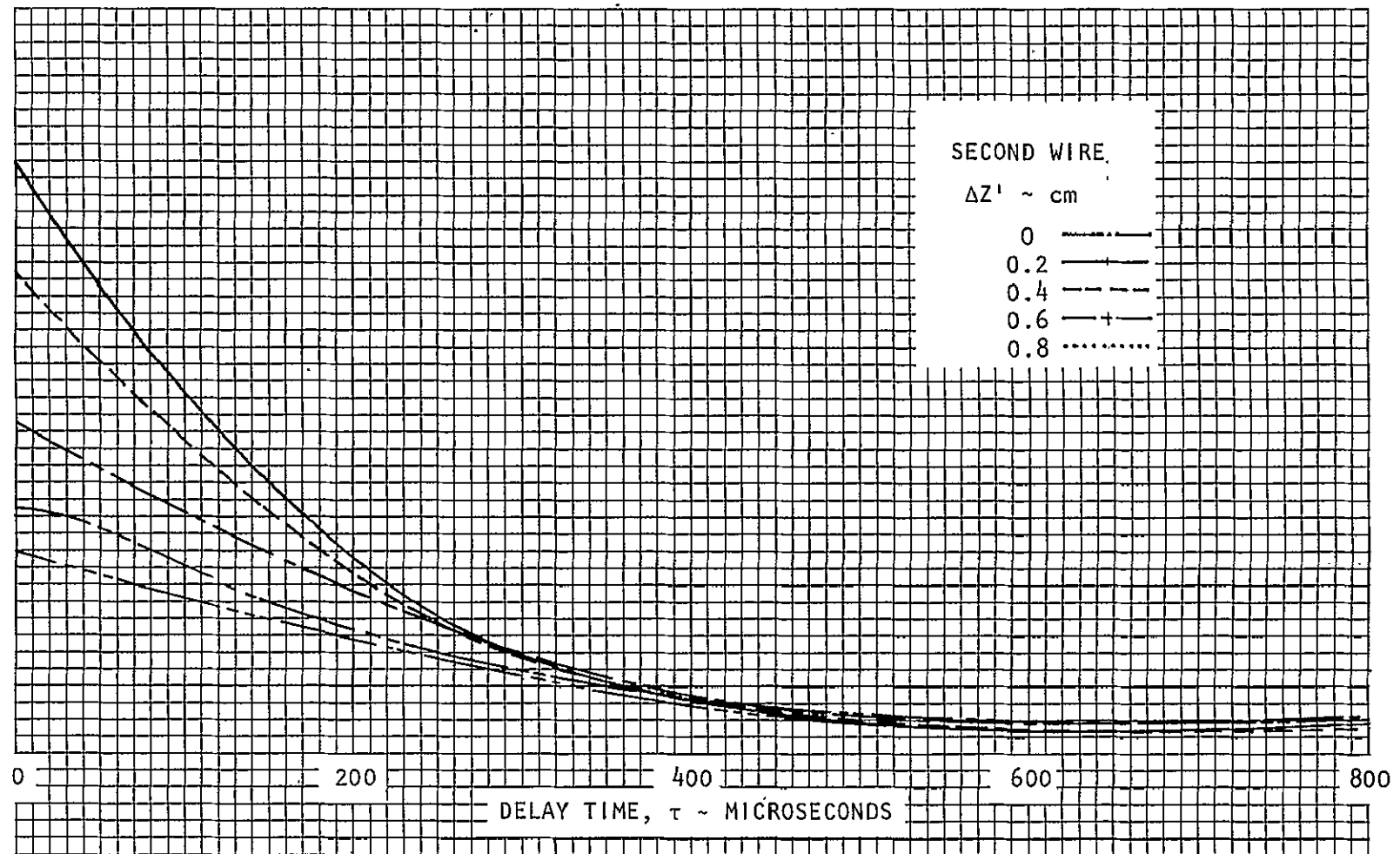


FIGURE 3-89: TRANSVERSE SPACE/TIME CORRELATIONS OF $\sqrt{u'^2 + w'^2}$ IN THE WAKE:
 AR-8 NOZZLE; $12.73 \times 1.59 \text{ cm}$; $X_N = 0.20 \text{ c}$; $\theta_N = 20^\circ$; $\text{NPR} = 1.1$;
 $R_c = 7.62 \text{ cm}$; $\delta_f = 60^\circ$; $L_{te} = 6.47 \text{ cm}$; $X' = 0.76 \text{ cm}$, $Y' = 0$,
 $Z'_1 = 0.1 \text{ cm}$.

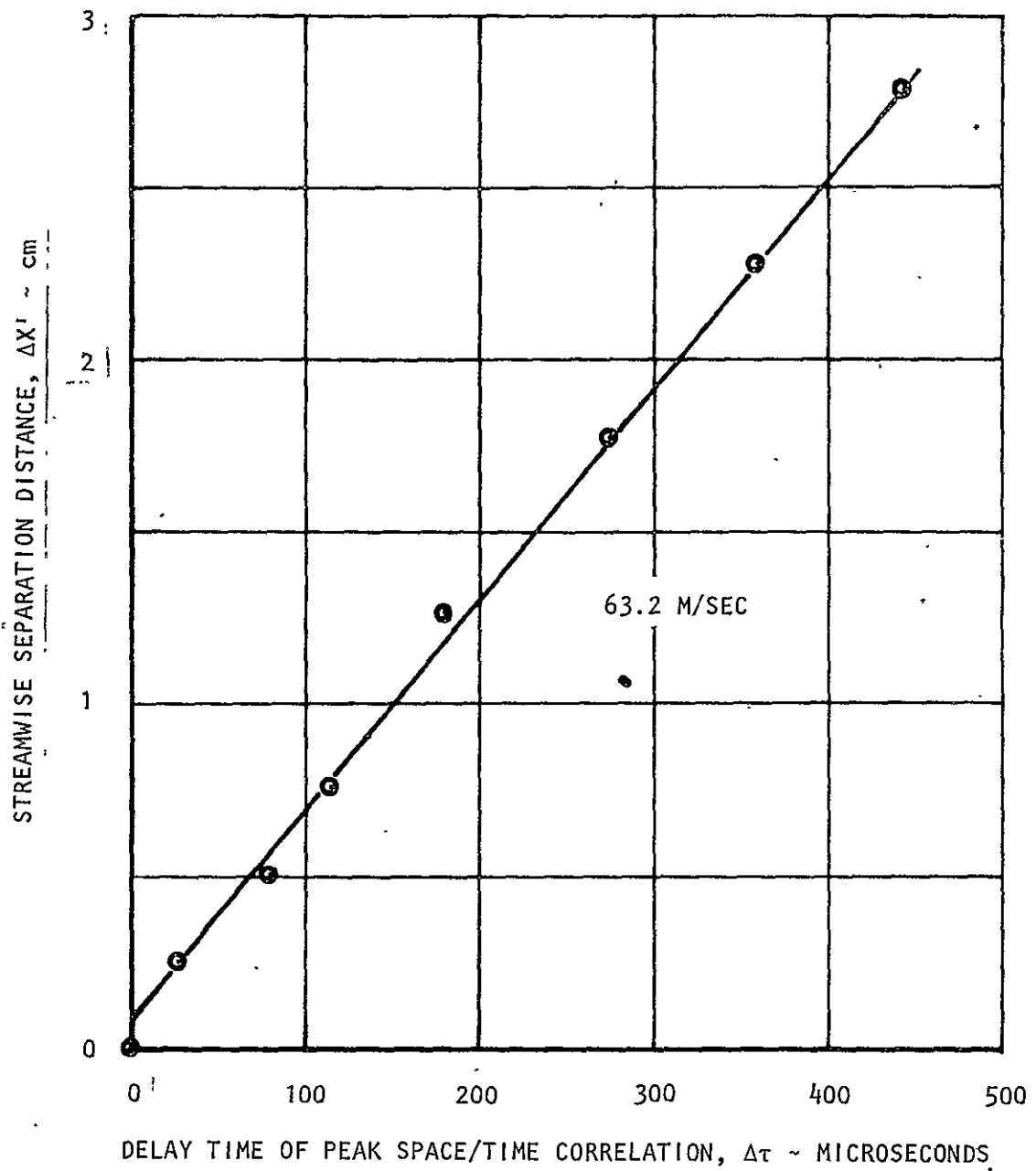


FIGURE 3-90. CONVECTION VELOCITY DETERMINATION; AR-8 NOZZLE;
 12.73×1.59 cm; $X_N = 0.20$ c; $\theta_N = 20^\circ$; NPR = 1.1;
 $R_c = 7.62$ cm; $\delta_f = 60^\circ$; $L_{te} = 6.47$ cm; $Z'_1 = 0.1$ cm,
 $Y = 0$.

(A) $X'_1 = 0.76$ cm

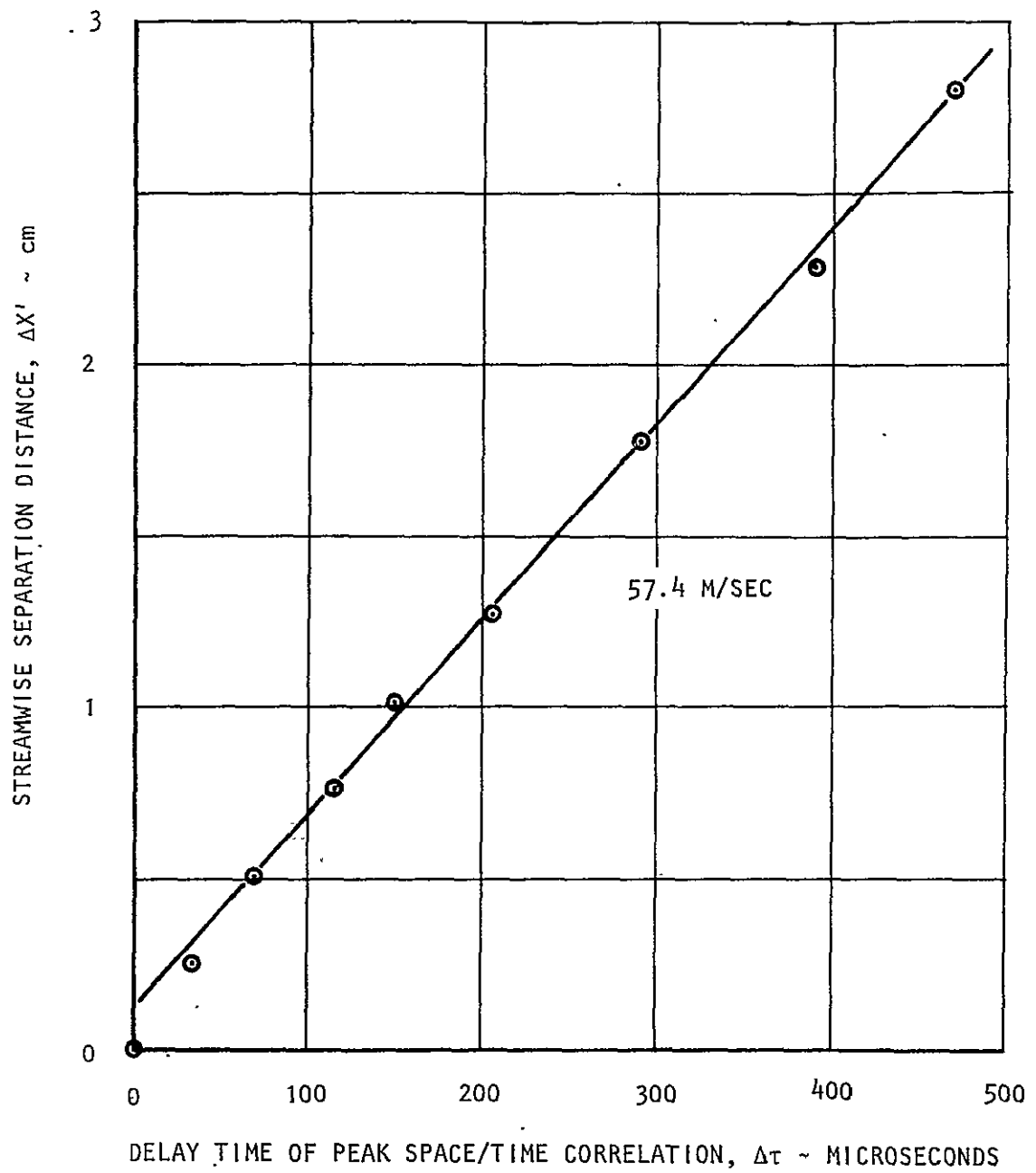


FIGURE 3-90 . (CONTINUED)
 (B) $X_1^1 = 1.59 \text{ cm}$

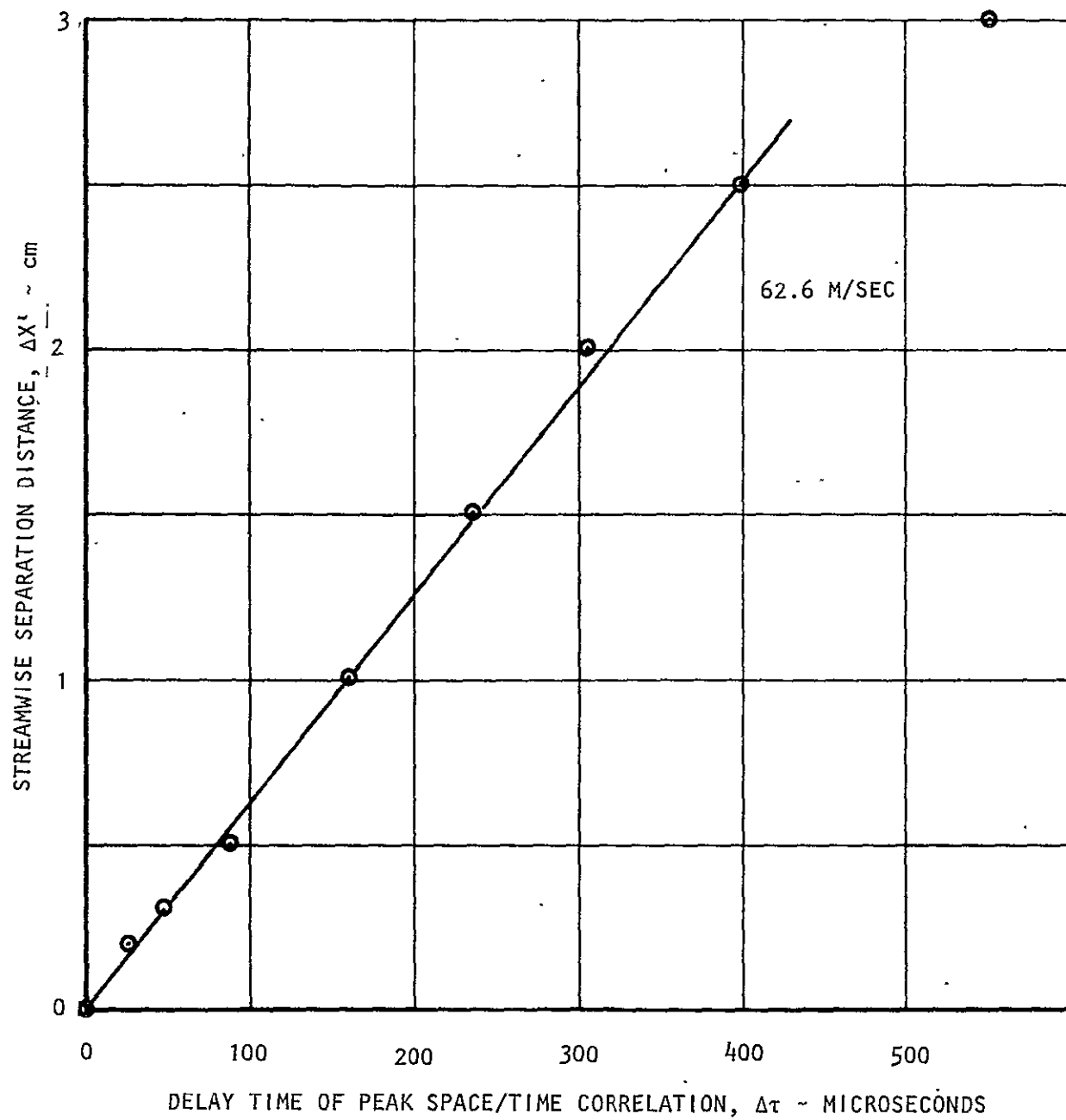


FIGURE 3-90, CONCLUDED)
 (C) $x_1^1 = 2.54 \text{ cm}$

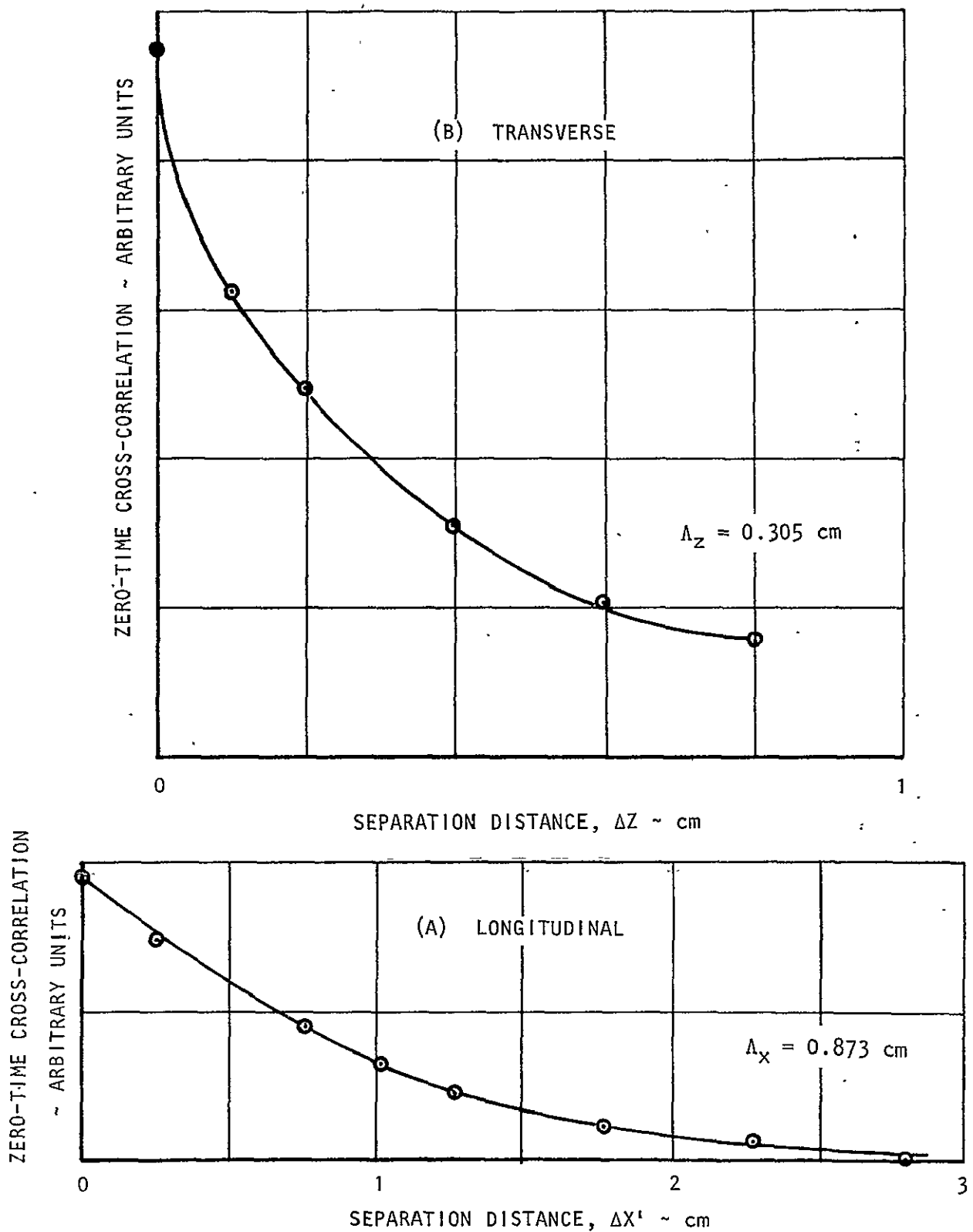


FIGURE 3-91. TURBULENT VELOCITY INTEGRAL SCALE DETERMINATION;
 AR-8 NOZZLE; $12.73 \times 1.59 \text{ cm}$; $X_N = 0.20 \text{ c}$; $\theta_N = 20^\circ$;
 $\text{NPR} = 1.1$; $R_c = 7.62 \text{ cm}$; $\delta_f = 60^\circ$; $L_{te} = 6.47 \text{ cm}$;
 $X_1^1 = 1.59 \text{ cm}$; $Y = 0$; $Z^1 = 0.1 \text{ cm}$

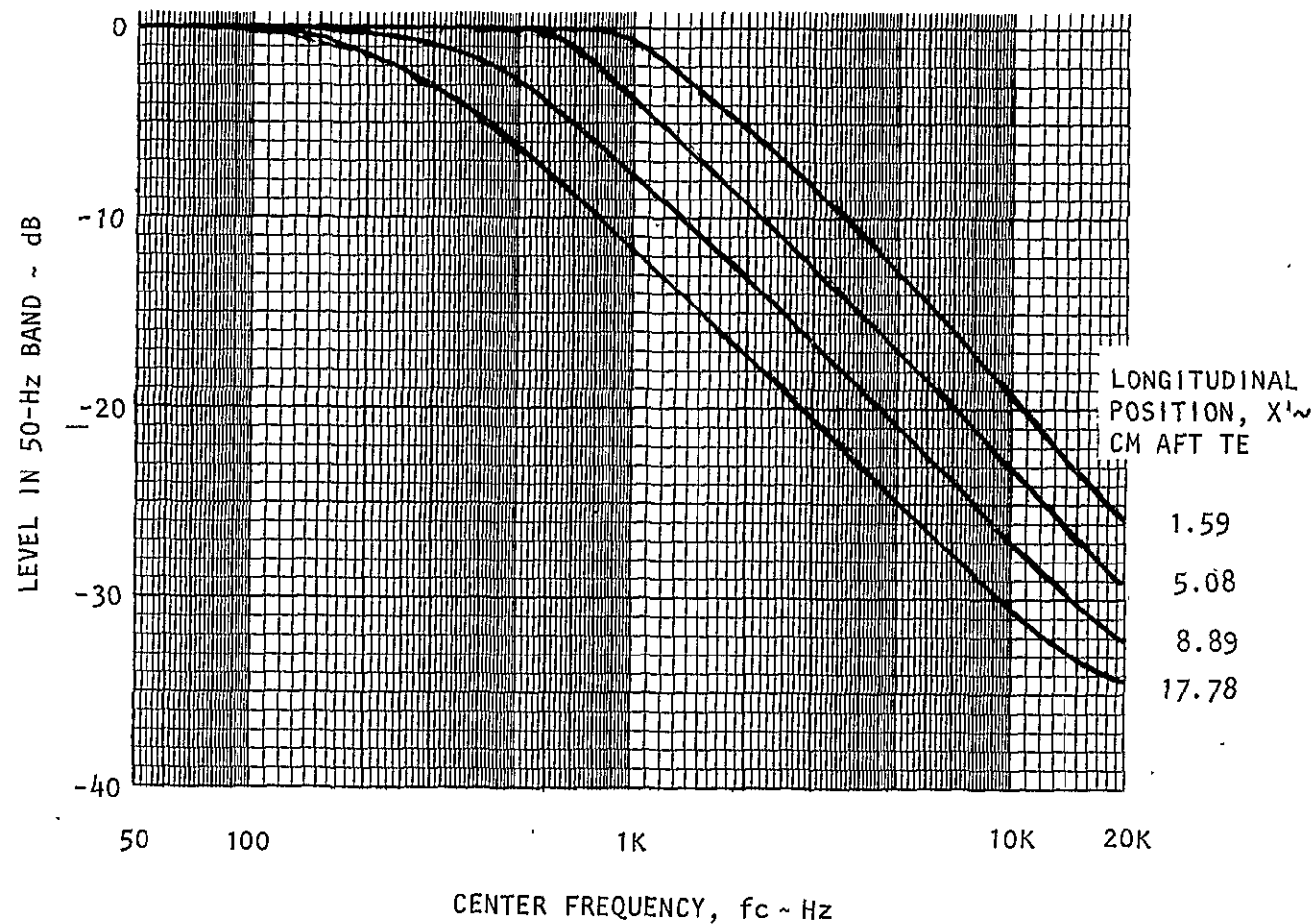


FIGURE 3-92: NARROW-BAND SPECTRA OF PEAK $\sqrt{u'^2 + w'^2}$ IN THE WAKE;
 AR-8 NOZZLE; $X_N = 0.2$ c; $\theta_N = 20^\circ$; NPR = 1.1;
 $R_c = 7.62$ cm; $\delta_f = 60^\circ$, $L_{te} = 6.47$ cm
 (A) STREAMWISE VARIATION; $Y' = 0$; $Z' = Z'_{MAX}$ INTENSITY

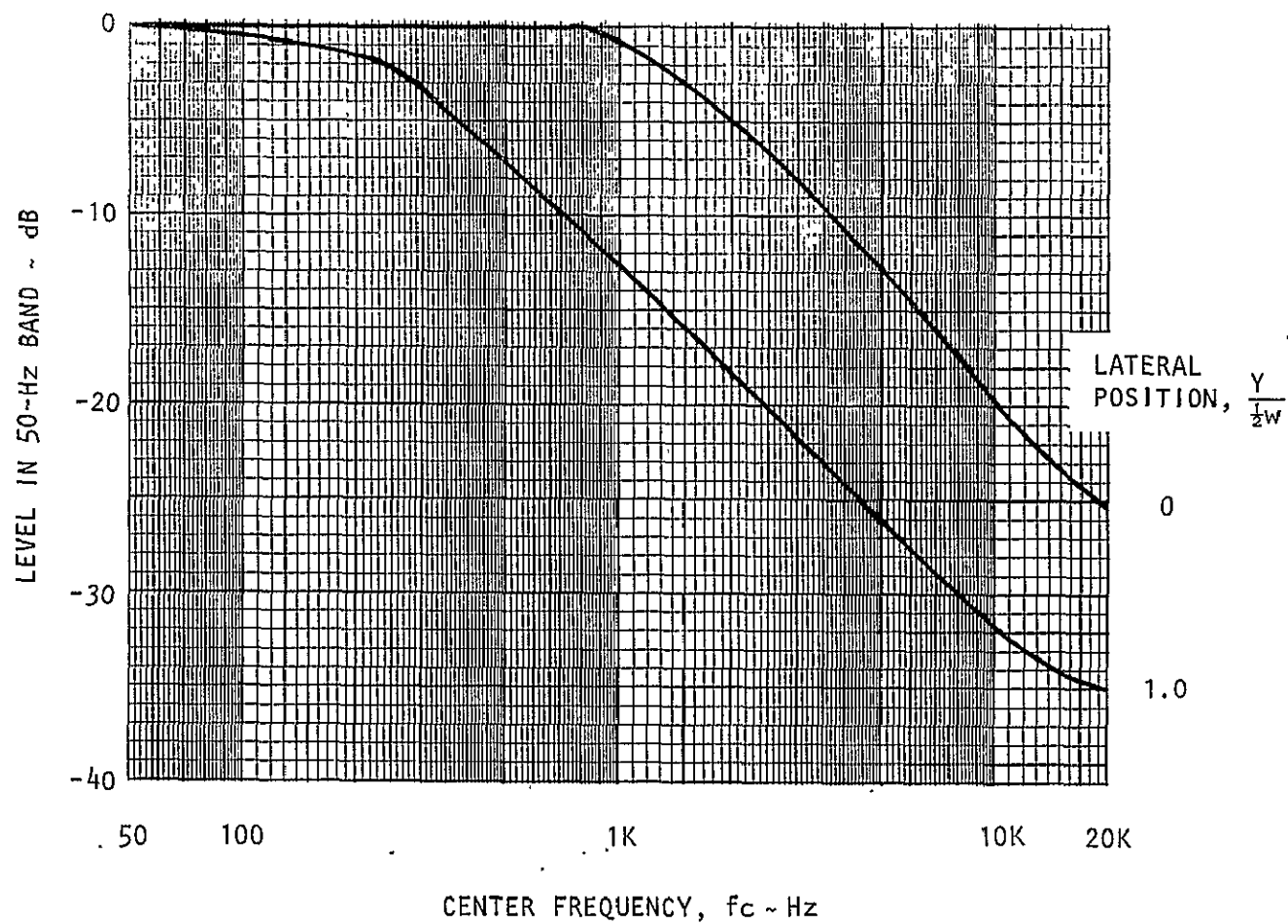


FIGURE 3-92. (CONTINUED)

(B) LATERAL VARIATION; $X' = 1.59$ cm; $Z' = 0.1$ cm

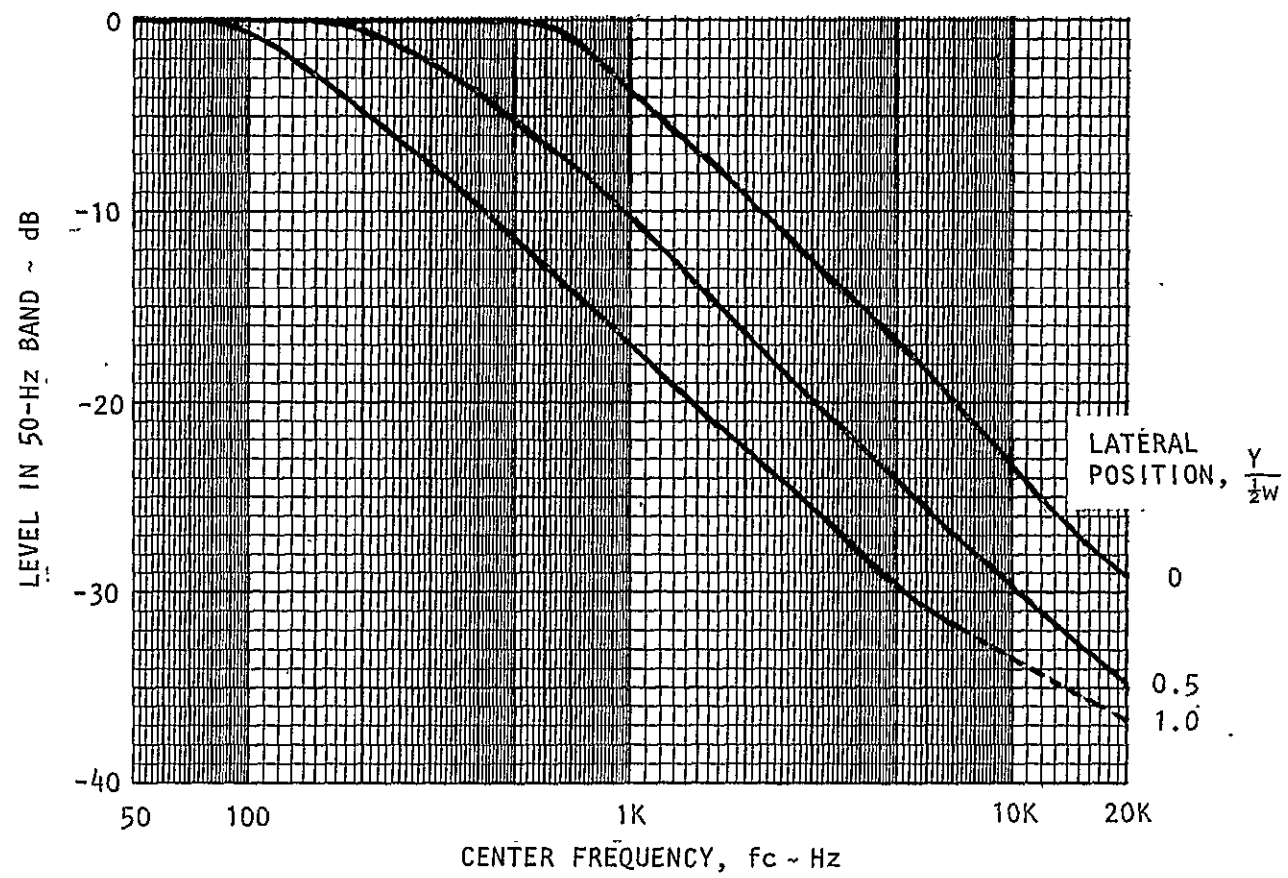


FIGURE 3-92.. (CONTINUED)

(C) LATERAL VARIATION; $X' = 5.08$ cm; $Z' = 0.1$ cm

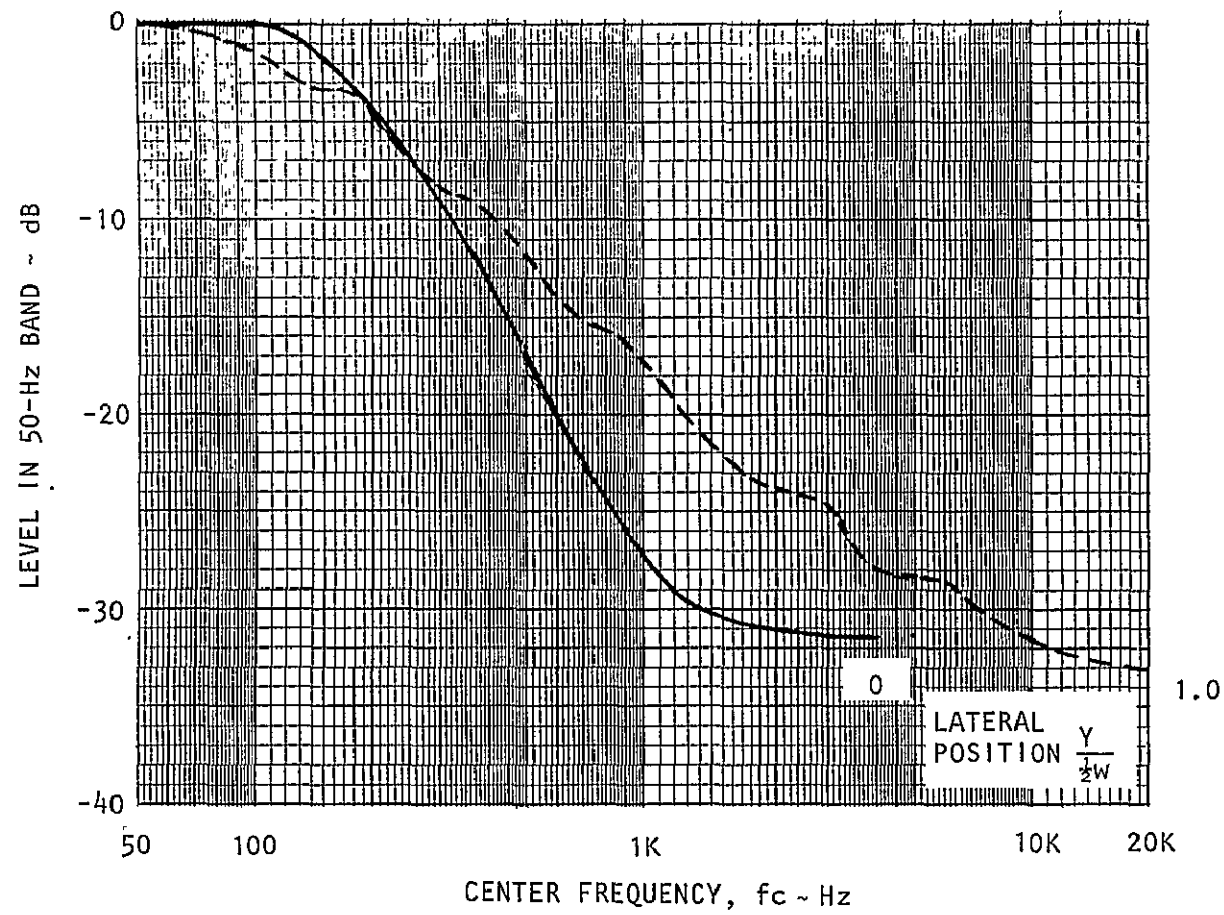


FIGURE 3-92.. (CONTINUED)
 (D) LATERAL VARIATION; $X' = 1.59 \text{ cm}$; $Z' = 9.02 \text{ cm}$

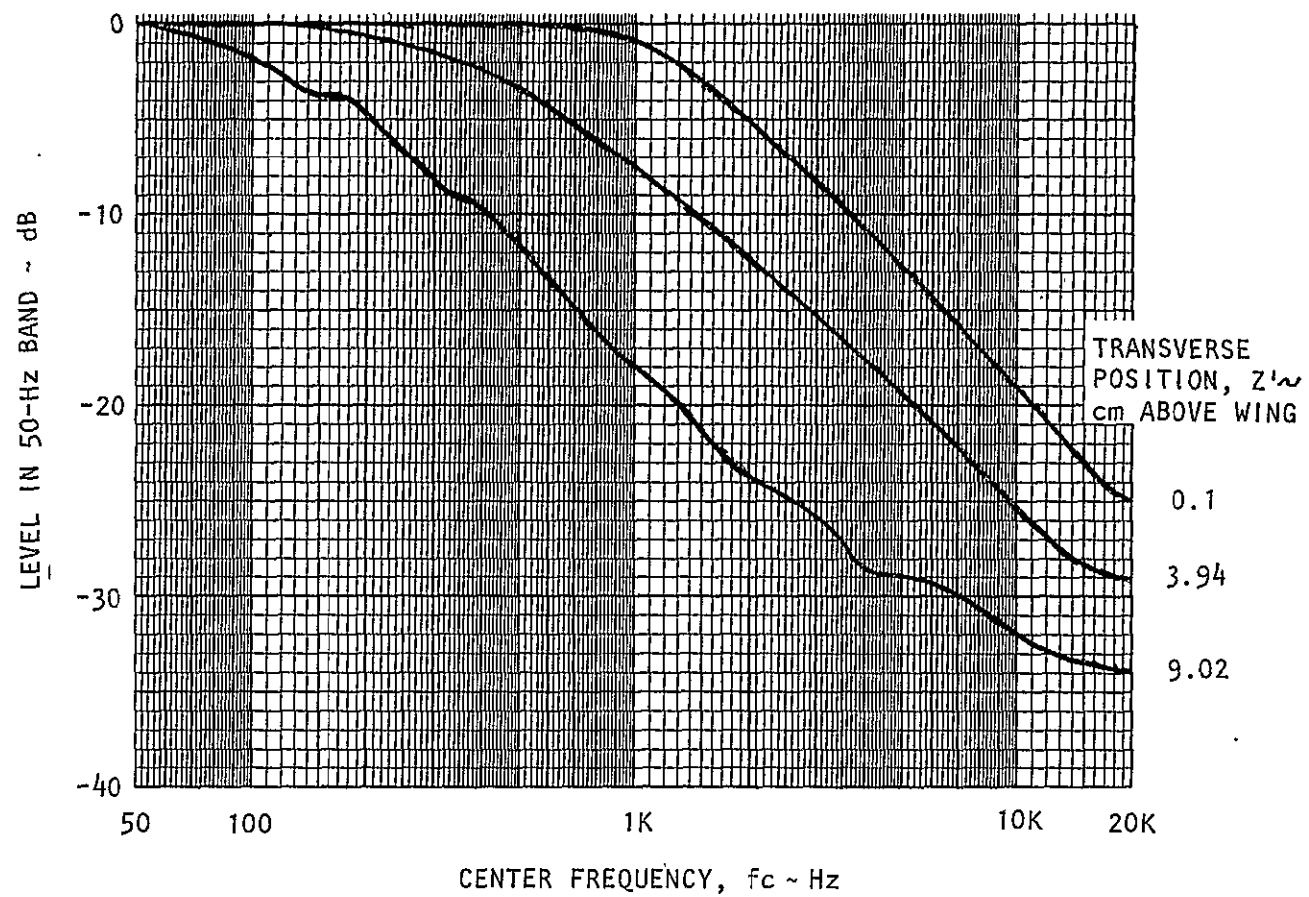


FIGURE 3-92. (CONTINUED)
 (E) TRANSVERSE VARIATION; $X' = 1.59$ cm; $Y = 0$

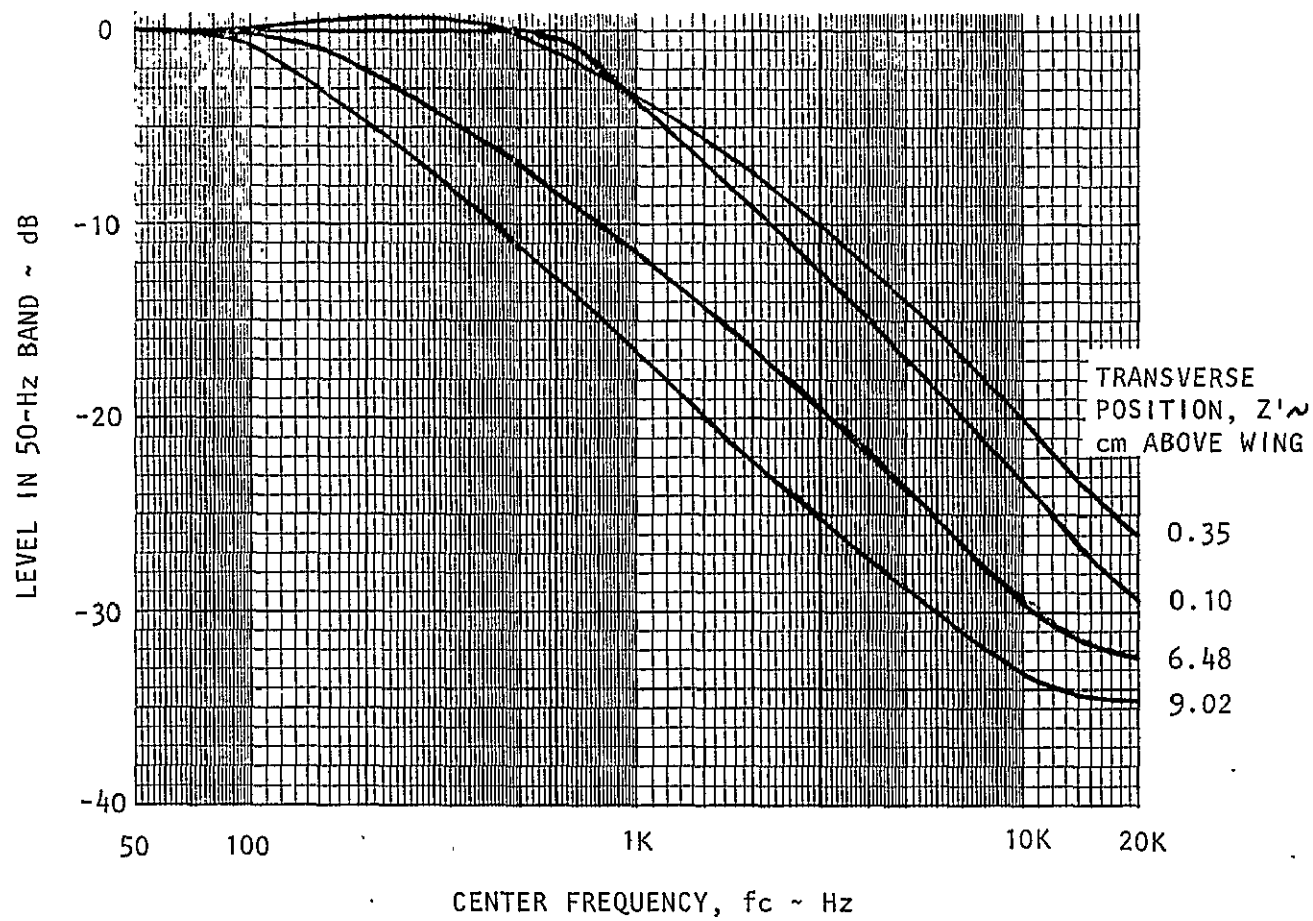


FIGURE 3-92. (CONCLUDED)
(F) TRANSVERSE VARIATION; $X' = 5.08$ cm; $Y = 0$

	NOZZLE	A_N , CM ²	TEST FACILITY
□	AR-2	10.13	ANECHOIC WIND TUNNEL
◇	AR-4	113.80	OUTDOOR RIG
◊	AR-8	113.80	OUTDOOR RIG
○	CIRC.	244.77	OUTDOOR RIG
Q	QCSEE	121.03	OUTDOOR RIG

OPEN SYMBOLS - $\delta_F = 30^\circ$; $L_{T.E.} = 24.82$ CM (6.48 CM FOR AR-2 NOZZLE).
 SOLID SYMBOLS - $\delta_F = 60^\circ$; $L_{T.E.} = 15.34$ CM (3.81 CM FOR AR-2 NOZZLE).

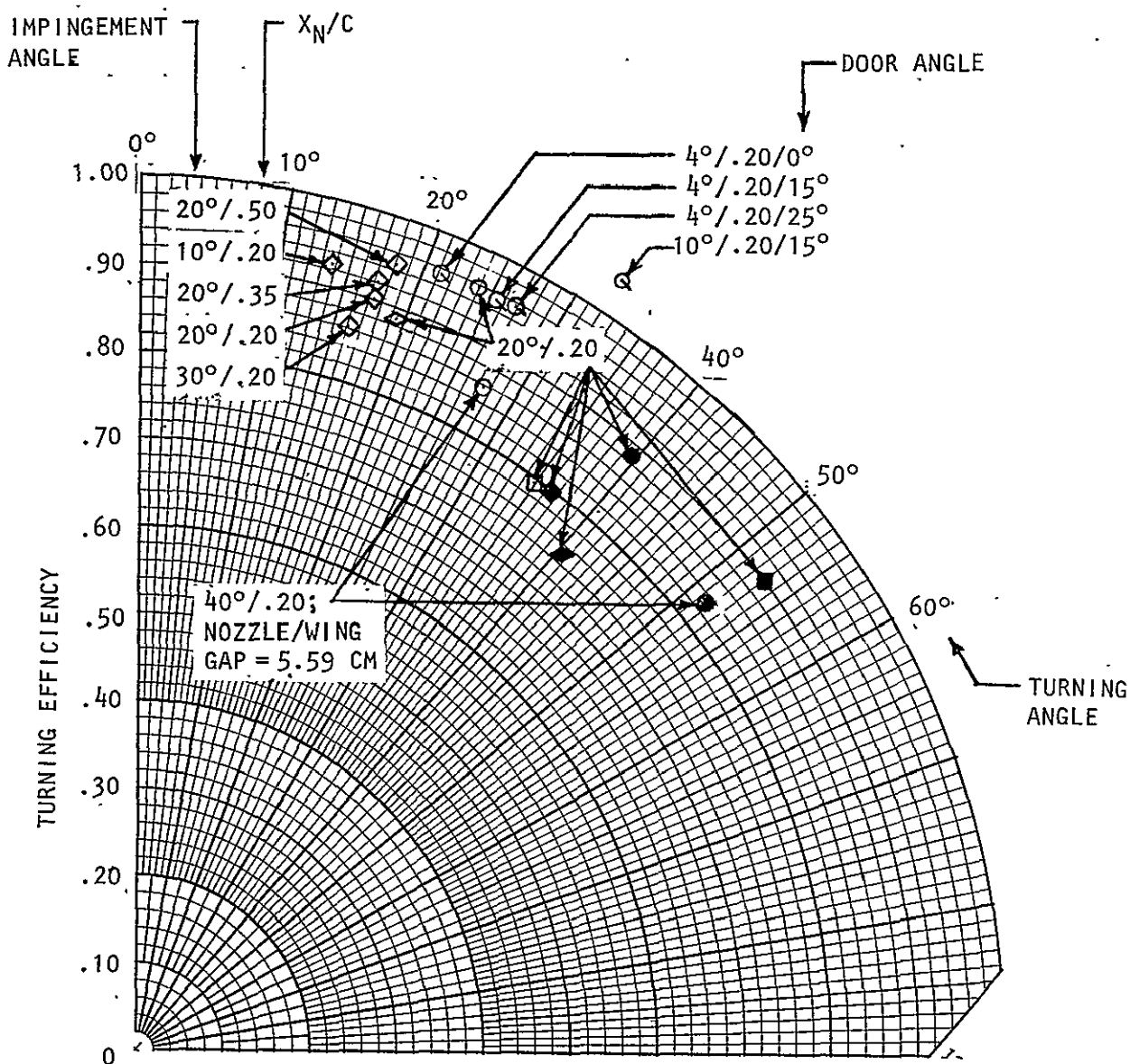


FIGURE 3-93. STATIC TURNING ANGLE AND EFFICIENCY. NO FLAP TREATMENT;
 $R_c = 18.06$ CM (5.08 CM FOR AR-2 NOZZLE), $V_j = 180$ -285 M/S.

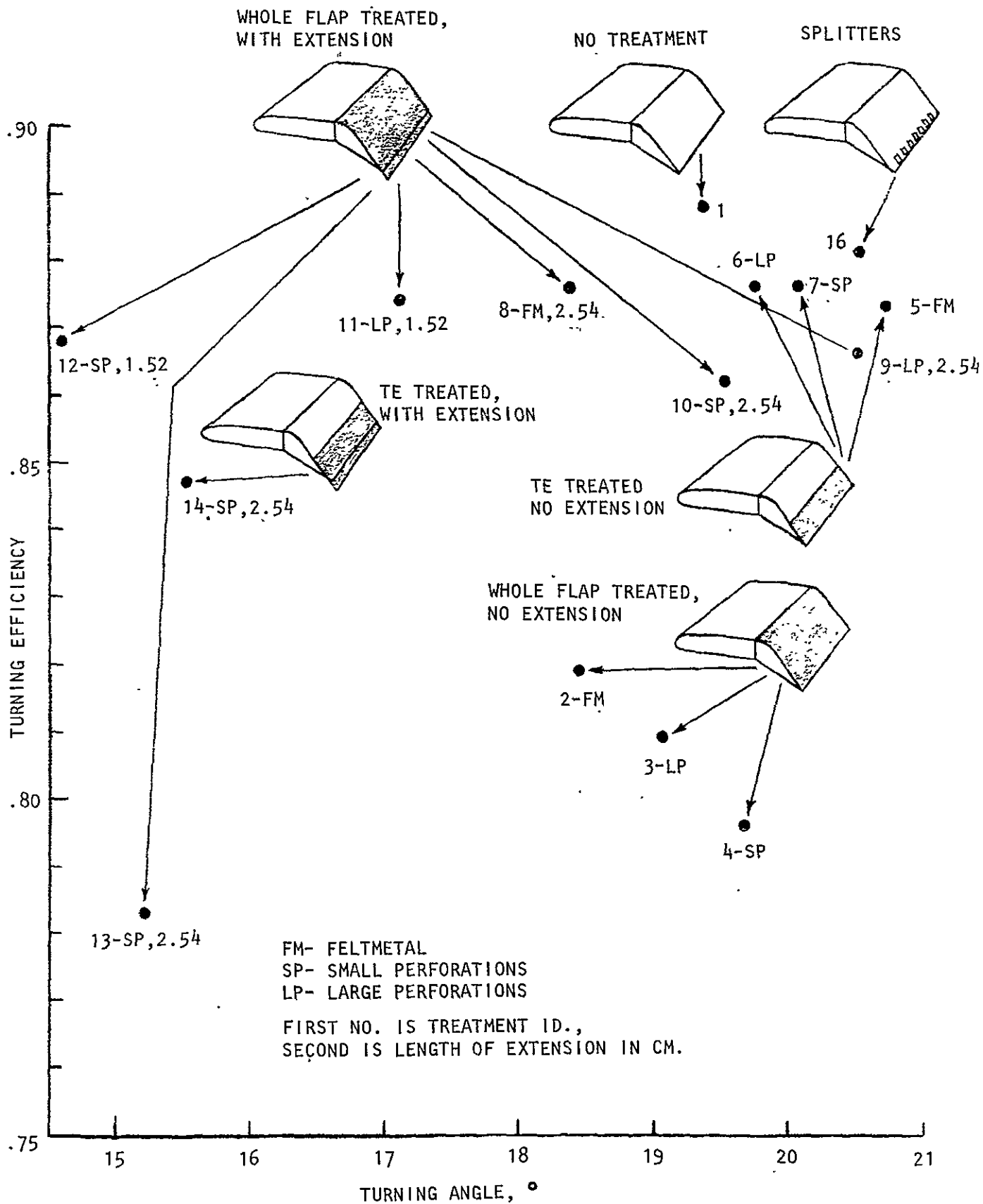
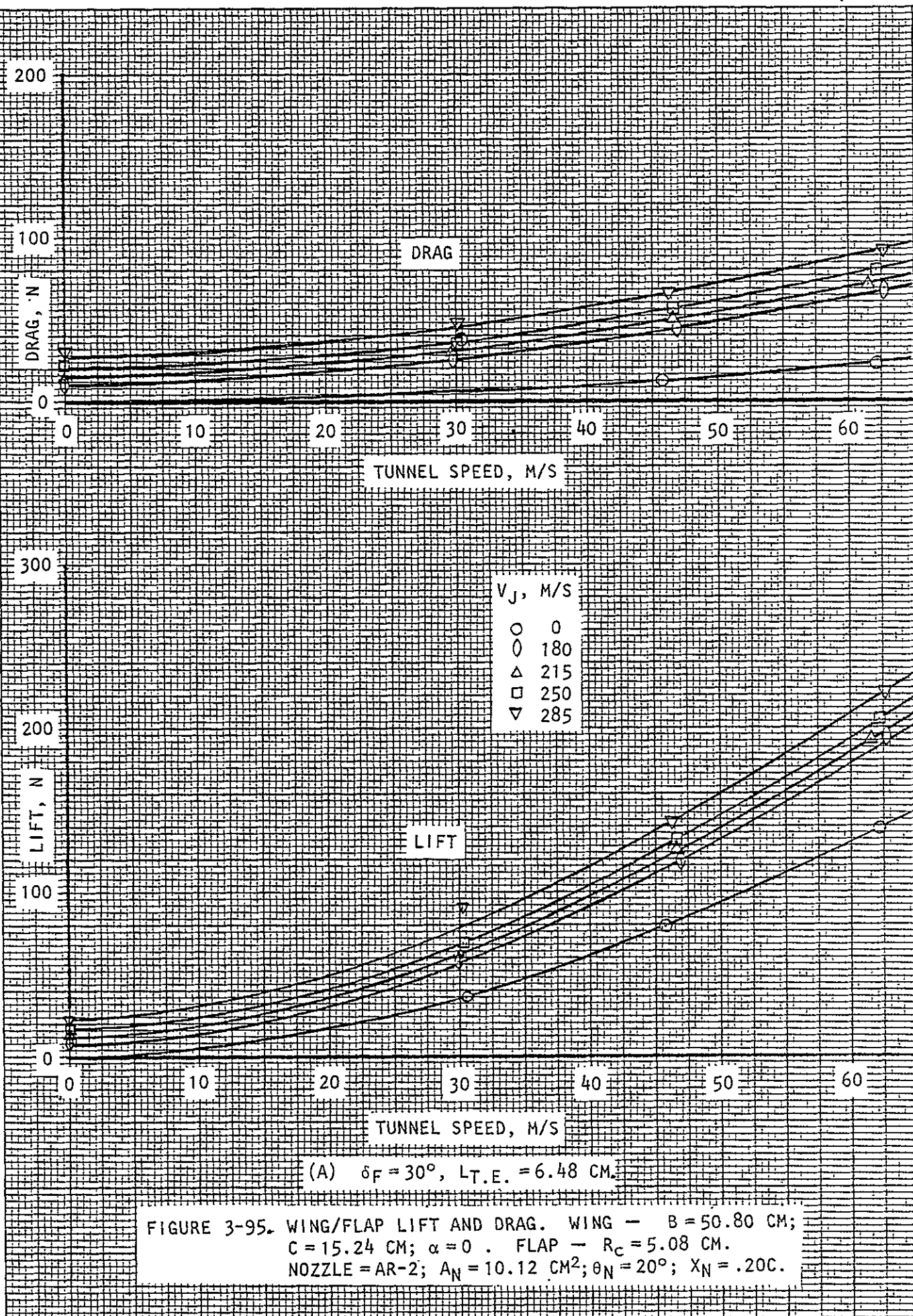
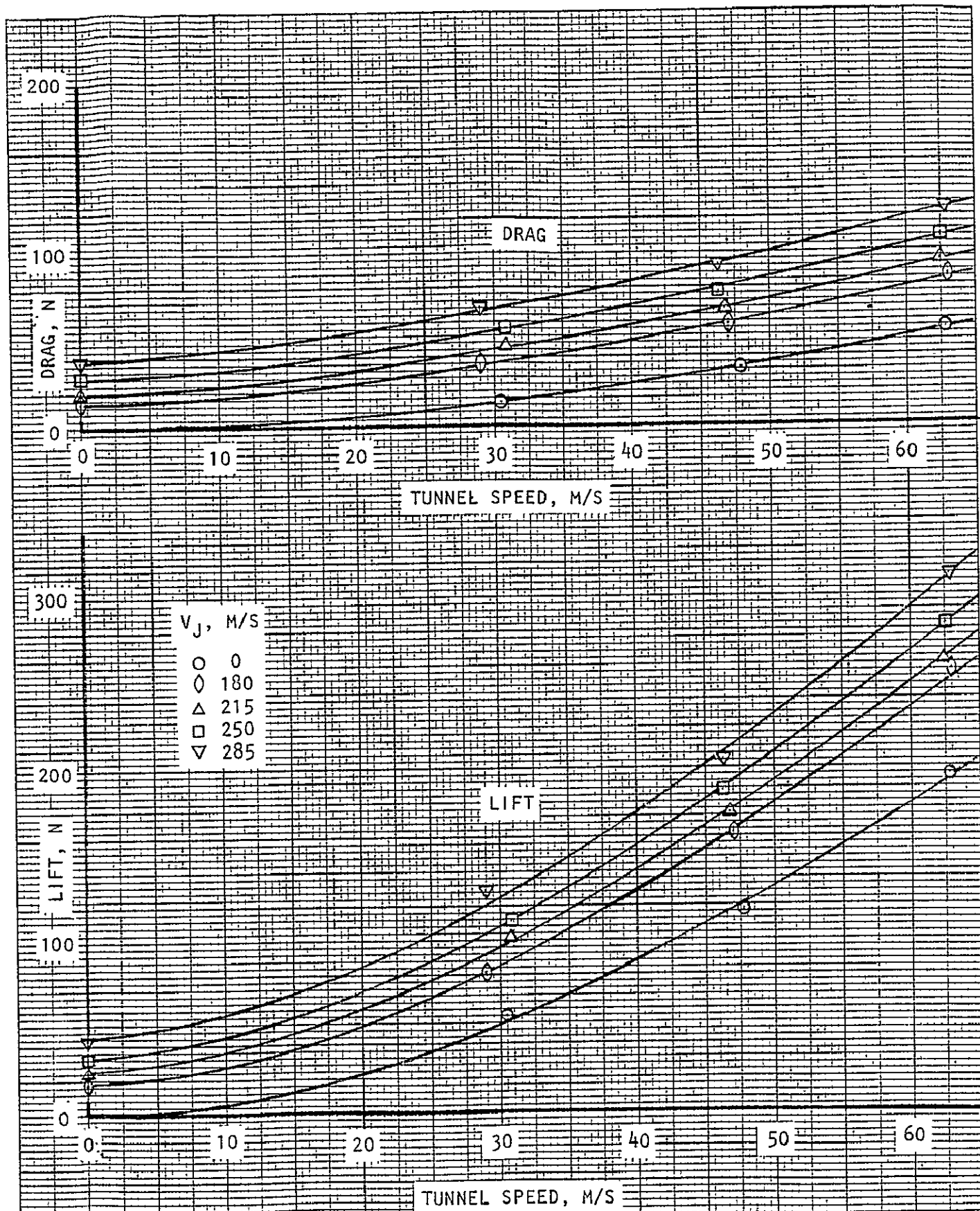


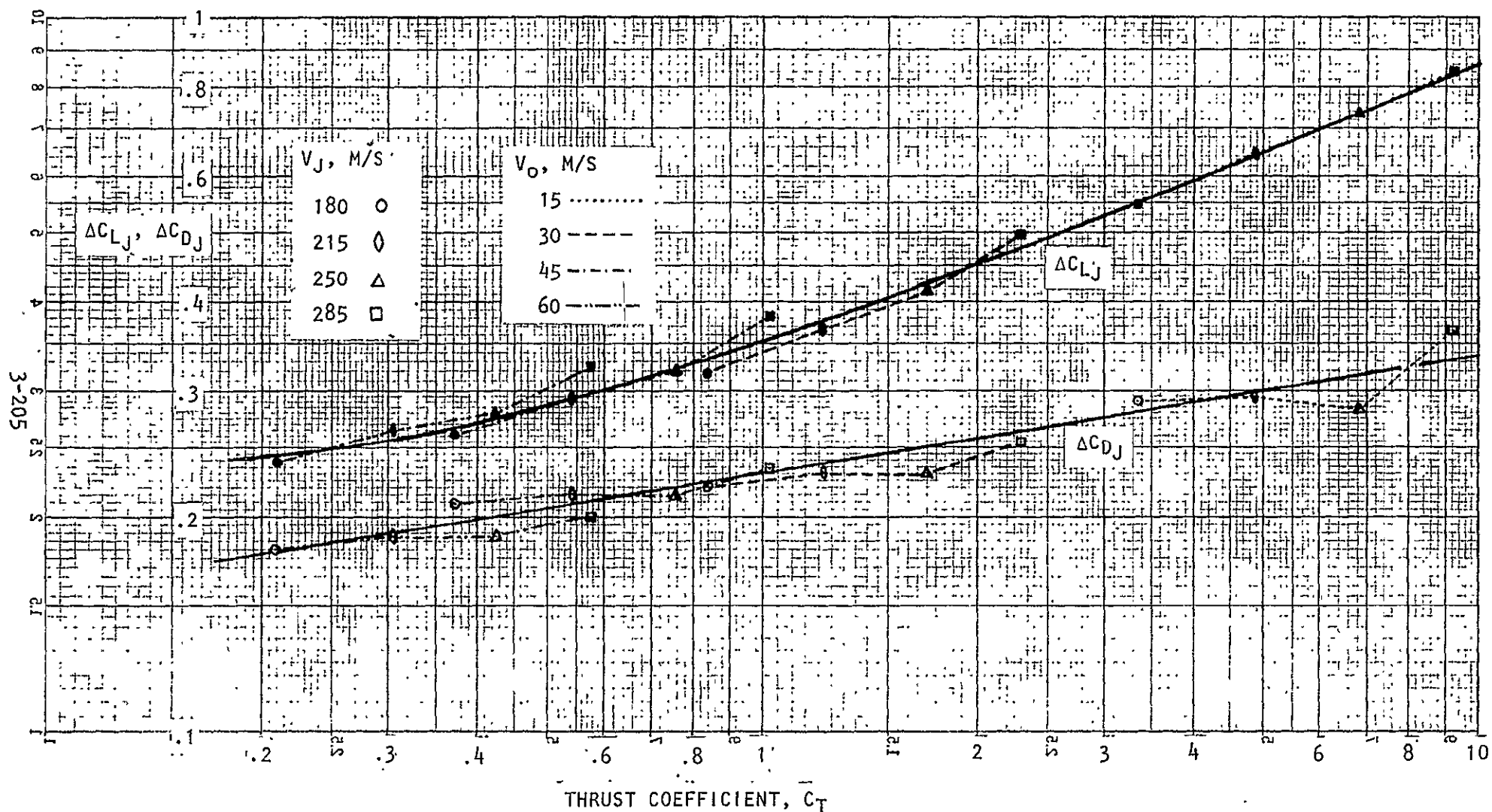
FIGURE 3-94. EFFECT OF FLAP TREATMENT ON STATIC TURNING ANGLE AND EFFICIENCY. NOZZLE - AR-8; $\theta_N = 20^\circ$; $X_N = .20C$; FLAP - $\delta_F = 30^\circ$; $R_C = 18.06$ CM; $L_{T.E.} = 24.82$ CM, $V_J = 180-285$ M/S.





(B) $\delta_F = 60$, $L_{T.E.} = 3.81$ CM.

FIGURE 3-95. CONCLUDED.

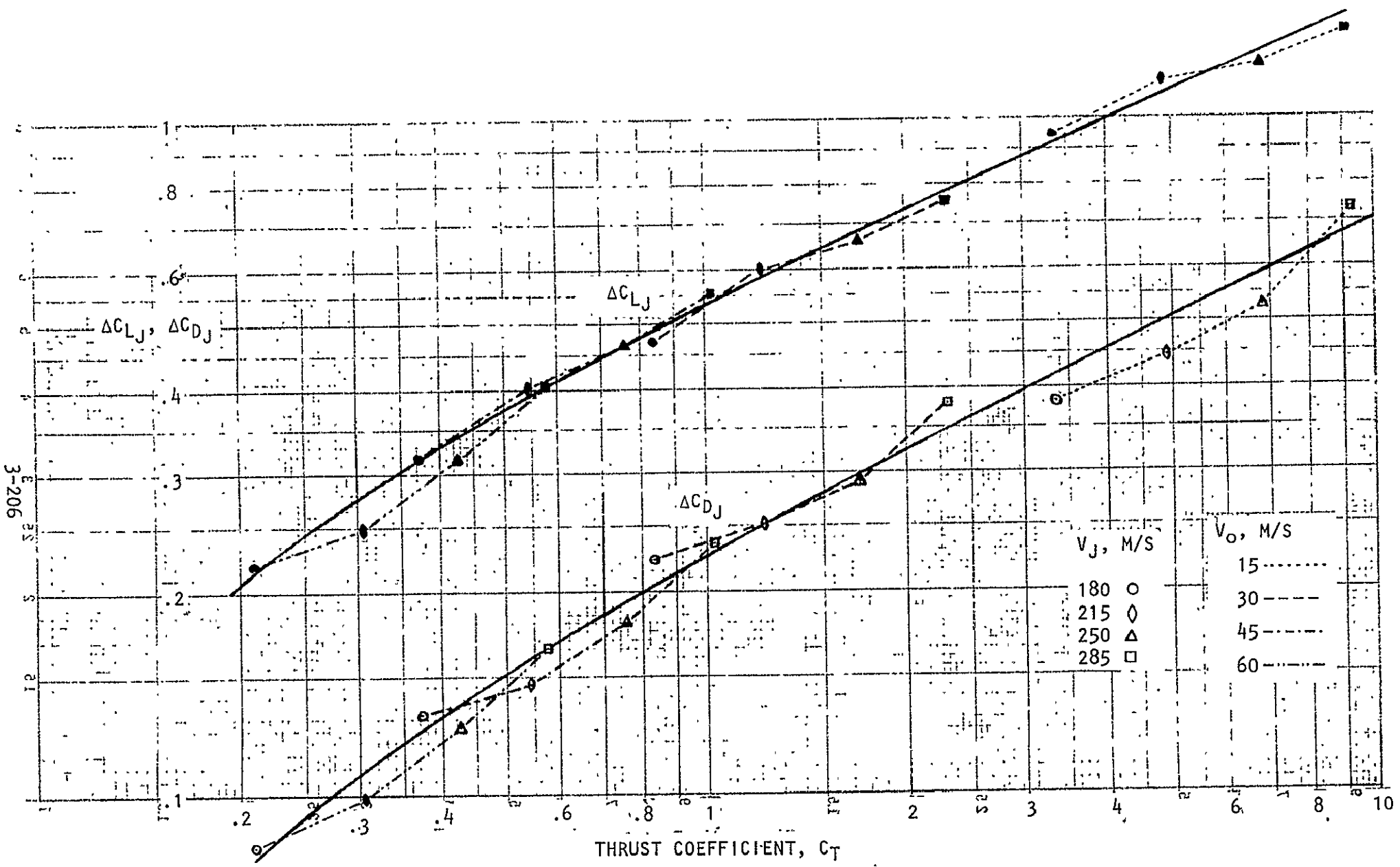


(A) $\delta_F = 30$, $L_{T.E.} = 6.48 \text{ CM.}$

FIGURE 3-96. LIFT AND DRAG COEFFICIENT INCREMENTS DUE TO JET AT FORWARD SPEED.

WING — $B = 50.80 \text{ CM}$; $C = 15.24 \text{ CM}$; $\alpha = 0^\circ$. FLAP — $R_C = 5.08 \text{ CM}$.

NOZZLE — AR-2; $A_N = 10.12 \text{ CM}^2$; $\theta_N = 20^\circ$; $X_N = .20C$.



(B) $\delta_F = 60^\circ$, $L_{T.E.} = 3.81$ CM.

FIGURE 3-96. CONCLUDED.

4.0 ACOUSTIC RESULTS

The farfield acoustic tests can be divided into four categories: Parametric Effects - systematic variations of performance and geometric parameters; Scale Effects - a comparison of large- and small-scale data; Forward Speed Effects - testing in an anechoic wind tunnel with freestream flow; and Effects of Noise Reduction Techniques - the application of acoustic treatment or trailing edge blowing to the flap. In addition, nearfield data were taken with an array of microphones to correlate with the farfield noise, surface pressure fluctuations were measured on the flap surface with Kulite transducers, and a simulated vectored thrust configuration was tested.

Data are presented in three principal ways: (a) one-third octave band spectral plots, (b) OASPL directivity plots, and (c) plots of OASPL versus nozzle exit velocity. Except where otherwise noted, all data are for the small-scale or large-scale baseline configuration defined in Table 4-1. Since most of the data presented are in the flyover plane ($\phi = 90^\circ$), elevation angle is not noted on the figures unless some other plane is used.

4.1 PARAMETRIC EFFECTS

Most of the parametric variations were carried out on the small-scale Anechoic Room test rig, with some supplementary work on the large-scale outdoor test rig. A baseline configuration was chosen and eight selected geometric parameters were varied about the baseline. The baseline values and range of parameter variations are shown in Table 4-1. The complete matrix of parameter variations could not be covered so a more limited matrix was selected which would give a good indication of the trends produced by the individual parameters. The matrix of test configurations is shown in Table 4-2.

4.1.1 Nozzle Shape

This parameter was investigated in two ways, first by varying nozzle aspect ratio using a series of rectangular nozzles and second by investigating other shapes which may prove suitable for USB propulsive nozzles.

4.1.1.1 Effect of Aspect Ratio - The effects of this parameter for the small-scale rig data are shown in Figures 4-1 through 4-3*. Examination of the one-third octave band spectra, Figure 4-1, shows that increasing the nozzle aspect ratio over the range from 1 (circular nozzle) to 8 produces a progressive reduction in mid-frequency noise. The amount of reduction (a maximum of about 6dB) does not vary with microphone position, but the reduction is spread over a wider frequency range at forward locations. The velocity exponents derived in Figure 4-2 increase slightly with increasing nozzle aspect ratio at all microphone locations. OASPL is plotted against microphone location for the flyover and 30° elevation planes in Figure 4-3. No significant change in directivity with nozzle aspect ratio is shown. The OASPL's reflect the mid-frequency changes shown in the spectra of Figure 4-1.

Large-scale model data are shown in Figures 4-4 through 4-6. Although only two nozzles were tested, the trends are similar to those shown for the small-scale model data.

4.1.1.2 Effect of Nozzle Shapes - Data for other than rectangular nozzle shapes (except the QCSEE) were taken only on the small-scale rig and are presented in Figures 4-7 through 4-9. These data have been scaled up to a 20.26-cm² nozzle area to aid in comparison with the previous data. The spectral plots show that in the low and mid-frequency range, the round, elliptical, and D nozzles all have similar noise levels, but at higher

* Data normalized to constant nozzle area assuming $SPL \sim 10 \log A_n$.

frequencies they diverge, with the D nozzle being the quietest and the circular the loudest. The indication is that the less the jet is spread spanwise across the wing/flap, the higher the noise level. The QCSEE nozzle data, however, appear to contradict this trend. The nozzle is very similar in shape to the D nozzle but has higher noise levels than any of the other nozzles at low and high frequencies.

It was suspected that the simulated variable-geometry doors of the QCSEE nozzle being open at 15° may have caused this increased noise level so the QCSEE nozzle was tested on the large-scale outdoor rig using various door angles. These data are presented in Figures 4-10 through 4-12. It is apparent that increasing the door angle significantly increases noise, particularly at high frequencies and to a lesser extent at low frequencies. It is concluded that the difference in noise level between the D and QCSEE nozzles is due to the variable-geometry doors being open, resulting in an increased effective nozzle edge length due to the gap between the bottom of the doors and the wing.

4.1.2 Nozzle Area

The effect of nozzle size for a given wing was investigated on the small-scale rig by testing two different size circular nozzles. The results are presented in Figures 4-13 through 4-15. It was expected that the noise of the larger nozzle would be increased by $10 \log \frac{A_{\text{LARGE}}}{A_{\text{SMALL}}}$ so the data for the small nozzle were increased by this amount (3dB in this case) when they were plotted. The spectra show excellent agreement at aft angles, but at forward angles the smaller nozzle seems to have a broader spectrum, i.e. it is higher at both high and low frequencies but is about the same in the middle frequencies. When OASPL is plotted against jet velocity (Fig. 4-14), the

exponents are almost identical at aft angles but the smaller nozzle has a significantly higher exponent at forward angles. The OASPL directivities plotted in Figure 4-15 show no significant differences between the two nozzles.

Thus it appears that the $10 \log \frac{A_{\text{LARGE}}}{A_{\text{SMALL}}}$ scaling method is valid. It should be noted, however, that if the whole model is not scaled, the flow field over the wing/flap surfaces and in the trailing edge wake may change. Thus the scaling law may deviate for different model geometries, depending on the dominant noise source.

4.1.3 Nozzle Impingement Angle

This parameter was tested on both the small- and large-scale test rigs. Small-scale data are shown in Figures 4-16 through 4-20. Except at 0° impingement, the spectra of Figure 4-16 show a general tendency toward lower noise in the middle and upper frequency ranges as the impingement angle is increased. It is suspected that the 0° case does not follow the same trends because of flow separation.

When the nozzle impingement angle is increased, the effective nozzle area becomes smaller, resulting in lower mass flow for a given velocity, and consequently in lower thrust. To isolate this thrust effect from the change in flow field due to the impingement angle, a correction was applied using measured flow rate data from the large-scale rig. The change in flow rate due to nozzle impingement angle is shown in Figure 4-17. A correction was applied to the data in the form $\Delta \text{dB} = 10 \log \frac{\text{FLOW}_{\theta_N = 0}}{\text{FLOW}_{\theta_N}}$, resulting in the spectra shown in Figure 4-18. The correction tends to collapse the spectra to some extent, but there is still a significant reduction in the middle frequencies with increasing impingement angle.

Figure 4-19 shows that the effect of impingement angle on velocity exponent is very small although there seems to be a tendency for it to reduce with increasing angle. No significant change in directivity can be observed in Figure 4-20. Results of varying nozzle impingement angle on the large-scale model are shown in Figures 4-21 through 4-23. Trends are similar to those for the small-scale model data.

4.1.4 Nozzle Vertical Position

This parameter was investigated only on the small-scale rig. The results are shown in Figures 4-24 through 4-26. The spectra (Figure 4-24) show a reduction in low-frequency noise as the nozzle is moved away from the wing. This effect is more pronounced at forward locations. No consistent trends with vertical location can be observed in the velocity exponents or directivities.

Since increasing the nozzle/wing separation is conducive to flow separation, a check was made on the effect of flow separation for a case where flow visualization was available. Figure 4-27 shows the spectra for a completely unattached flow condition, a case where the flow separates at the flap knee, and one where the centerline flow is attached right down to the flap trailing edge. Early separation at the knee is felt primarily in the mid-frequency range, whereas complete separation reduces noise throughout the spectrum, resulting in levels close to those of the jet alone. The flow patterns of the partially and fully attached cases can be confirmed by reference to the Schlieren pictures of Figure 3-11.

4.1.5 Flow Path Length

This parameter, defined as the distance along the surface from the nozzle exit to the flap trailing edge, was varied in two ways, first by positioning the nozzle at different chordwise stations and second by varying the flap length.

4.1.5.1 Nozzle Chordwise Position - The results of varying this parameter on the small-scale rig are shown in Figures 4-28 through 4-30. Changing the nozzle position from 20% chord to 35% has little effect on the level of the noise but does appear to shift the spectrum to a higher frequency range. When the nozzle is shifted to the 50% chord position; however, there is a considerable increase in mid-frequency noise in addition to the frequency shift. Velocity exponents show no consistent trends and directivity does not appear to be affected. Large-scale data (Figures 4-31 through 4-33) show a similar trend in frequency shift, but no increase in levels at the 50% chord position.

4.1.5.2 Flap Length - This parameter was varied only on the small-scale rig. The results are shown in Figures 4-34 through 4-36. Three flap trailing edge lengths were used: 9.14 cm, 10.46 cm, and 11.79 cm, resulting in flow path lengths of 20.44 cm, 21.76 cm, and 23.08 cm. The spectra show no change in sound pressure levels, but the spectrum is shifted to lower frequencies as the trailing edge length is increased. The velocity exponents show no significant change, nor do the OASPL directivities.

4.1.5.3 Flow Path Length Correlation - Since the variations of both nozzle chordwise position and flap length show that the spectrum is shifted to a lower frequency as the flow path length is increased, the Strouhal numbers for the spectra were calculated using flow path length as the linear dimension and jet exit velocity; i.e., Strouhal number = $\frac{f \times L_f}{V_j}$. The resulting non-dimensionalized spectra are shown in Figure 4-37. The spectra correlate very well using this frequency parameter for a given microphone position.

4.1.6 Flap Angle

The effects of this parameter were examined initially at fixed microphone positions. Small-scale data (Figures 4-38 through 4-40) show a tendency for the SPL's at the low-frequency end of the spectrum to increase with flap deflection. This tendency is greater at forward microphone positions. Velocity exponents tend to increase slightly with flap angle. The directivity plots in Figure 4-40 show a significant change in OASPL directivity with flap angle, indicating that the noise field tends to rotate with the flap.

Large-scale model data are shown in Figures 4-41 through 4-43, where a comparison is also made with nozzle-alone data. As far as flap deflection is concerned, the same trends are apparent as for the small-scale data and the familiar large increase in low-frequency noise is apparent when compared to the nozzle alone. Since the noise field appears to rotate with the flap, a comparison is made in Figure 4-44 for three flap angles at a constant angle relative to the flap upper surface (θ''). The spectra are plotted against the Strouhal number, which in this case includes the flap deflection angle in radians. Good agreement is shown between the spectra at three different flap angles, indicating that noise directivity is dependent on the flap direction rather than the nozzle or wing orientation. When the OASPL directivities are plotted against θ'' (Figure 4-45), excellent agreement is shown between the 30° , 45° , and 60° flap cases, but the 0° case shows a little more noise radiated in the forward direction.

4.1.7 Flap Radius of Curvature

This investigation was carried out only on the small-scale rig, using three radii for a fixed flap angle of 30° . Flap trailing edge lengths were changed to keep the flow path length constant. Reference to Figures 4-46 through 4-48 shows that radius of curvature has a negligible effect on farfield noise.

4.1.8 Jet Exit Velocity

The effects of jet velocity for the small-scale model are shown in Figures 4-49 and 4-50. The spectra show that noise progressively increases with jet velocity and the spectrum simultaneously shifts to a higher frequency range. OASPL directivities show a greater increase in noise in the aft quadrant as the velocity increases. Figure 4-51 shows that if a relationship of $75 \log \frac{V_j}{V_{ref}}$ is used for the SPL and $\frac{fxL_f}{V_j}$ is used to non-dimensionalize the frequency, the spectra collapse well into a single curve for the velocity range covered. Data from the large-scale rig, shown in Figures 4-52 and 4-53, show similar trends to those of the small-scale rig.

4.1.9 Jet Exit Temperature

The effect of temperature was investigated on the small-scale rig using two temperatures, ambient (25°C) and 93°C. Spectra for three angular positions are plotted in Figure 4-54. Reduction in the high-frequency noise for all locations is evident for the higher temperature condition. Figure 4-55 shows that the higher temperature case also has a lower velocity exponent at all three locations. The OASPL directivities plotted in Figure 4-56 are unaffected by jet temperature.

4.2 SCALE EFFECTS

A limited amount of data were taken to investigate acoustic scale effects with USB configurations by testing geometrically similar configurations of two sizes. Small-scale data were obtained in the anechoic room using a model with a nozzle area of 20.26 cm² and large-scale data were taken on the outdoor Acoustic and Performance Facility using a nozzle area of 113.8 cm². Thus the linear scale ratio between the two models is 2.37. Comparisons were made for rectangular nozzles of aspect

ratio 4 and 8, with and without the wing/flap in position. The data are compared by scaling the small-scale data to the large-scale conditions: SPL's are increased by $20 \log 2.37$, frequencies are shifted down by a factor of 2.37, and a distance correction of $20 \log \frac{2.4}{6.1}$ is applied. In addition, atmospheric attenuations were corrected to the appropriate distances and frequencies.

4.2.1 Nozzle-Alone Data

Comparisons are shown for the nozzle alone in Figures 4-57 through 4-59. OASPL directivities are plotted in Figure 4-57 for both nozzles and three velocities. Agreement is generally good between the two sets of data although there are some irregularities in the small-scale data at forward locations for the AR-8 nozzle. These irregularities are believed to be the result of problems that were experienced with the data acquisition system early in the test program. One-third octave band spectra are compared in Figure 4-58 and agreement is generally good except for the AR-8 nozzle above 10kHz. The variation of OASPL with nozzle exit velocity is shown to be fairly close for both nozzles in Figure 4-59.

4.2.2 Nozzle with Wing/Flap

One-third octave band spectrum comparisons are shown in the flyover and 30° elevation planes in Figures 4-60 and 4-61 and OASPL vs velocity comparisons in Figures 4-62 and 4-63. Excellent agreement is observed in both cases. The OASPL directivities plotted in Figure 4-64 show good agreement in the aft quadrant, but the small-scale data seem to be slightly higher forward of the 90° point.

From the degree of agreement between the two sets of data, it appears that the methods used to scale the data are adequate for geometrically similar models.

4.3 FORWARD SPEED EFFECTS

The effect of forward speed on propulsion system noise has been investigated in several NASA and industry programs. It is generally found, at least in model tests, that noise levels, in terms of OASPL or PNL, decrease in proportion to some power of the relative velocity V_R , where V_R is equal to jet velocity V_j minus forward velocity V_0 . The reduction from the effects of forward speed is attributed to the decrease in the shear stresses in the mixing layer between the jet and the freestream as forward speed increases.

It was found in an investigation of forward speed effects on externally blown flap (EBF) noise with underwing nacelles (Reference 2 and further unpublished Lockheed results) that forward speed effects depend to a significant extent on the frequency range considered. This dependence was also observed in the present program, as is illustrated in Figure 4-65. The figure compares the static and 62 m/sec spectra of one of the test configurations at the flyover microphone, with shading indicating noise reduction with forward speed. The figure shows a reduction of about 4 dB to the left of the peak-noise frequency and of about 0.5 dB to the right. Since differential effects are the general rule, the data in the above-peak and below-peak frequency ranges were analyzed separately. This approach provides more information than does OASPL or PNL.

Three configurations were tested. The results are presented in the following figures -

Frequency Range -	<u>Low</u>	<u>High</u>
30° Flap -	4-66(A)	4-66(B)
60° Flap	4-66(C)	4-66(D)
30° Flap, Nozzle Spaced Off-Wing -	4-66(E)	4-66(F)

The figures show the average SPL increment due to forward speed against V_R (log scale), with the six microphones in the flyover plane at the top and the three microphones in the 30° elevation plane at the bottom. Negative increments mean that forward speed reduces noise. The following conclusions can be drawn from the data:

- ° The relative velocity ($V_R = V_J - V_0$) is an appropriate correlating parameter, adequately accounting for the effects of both V_J and V_0 and yielding curves that in most cases are linear over significant ranges. (Relative velocity ratio, V_R/V_J , correlates forward speed noise data in many cases, such as the EBF results previously mentioned and jet noise data. For unknown reasons, however, V_R/V_J does not adequately correlate the present results.)
- ° In the low-frequency range with the nozzle in contact with the wing, forward speed reduces noise at all V_R 's above about 125 m/s. (Typical STOL aircraft V_R 's are 200 m/s in climbout and 100 m/s on approach, although variations of 50 m/s or more can easily arise from changes in the aircraft or engine design.) The SPL increment is proportional to $\log V_R^{-2}$ over most of the range, and ranges up to 4 dB. With the nozzle spaced off the wing the noise reduction in the low-frequency range (Figure 4-66(E)) is typically 1-3 dB, with little dependence on relative velocity.
- ° In the high-frequency range the noise increment is again proportional to $\log V_R^{-2}$. The transition from noise increases to noise decreases, however, moves up to 150-170 m/s at most microphones. Thus the effect of forward speed is to decrease high-frequency noise by of the order of 2 dB during climbout and to increase it by a similar amount on approach.

- ° With 30° flaps and the nozzle in contact with the wing the V_R^{-2} relationship holds only to a jet velocity of 250 m/s. Above this jet velocity Δ SPL breaks sharply upward. This may be due to shocks in the flow over the flaps but the 60° flap configuration, which should have shocks at least as strong as the 30°, shows little if any break.
- ° The patterns described above are largely independent of microphone location, with one significant exception: in the high-frequency range the aft microphones in the flyover plane exhibit large positive increments (up to +15 dB), although the low-frequency increments and the increments in both frequency ranges at the 30° elevation microphones show no such excursion. Spectra illustrating the high-frequency noise increases are shown in Figure 4-67.

From the locations of the aberrant microphones relative to the flap plane it might be conjectured that the anomalies are caused by impingement of the deflected stream on the microphones. Investigation indicates, however, that the observed changes are probably not caused by impingement. Figure 4-68 presents spectra from a large-scale test in which the deflected stream was seen to buffet the microphone. The varied and inconsistent wind-noise spectra of Figure 4-68 in no way resemble the forward speed spectra of Figure 4-67, which exhibit the usual USB noise spectrum shape.

The same phenomenon - high-frequency noise increases on aft microphones - was observed in the EBF tests previously referenced,

on microphones that were definitely not exposed to the deflected jet. It is concluded that aft high-frequency noise increases with increasing forward speed are a real phenomenon of both EBF and USB lift systems.

4.4 NOISE REDUCTION TECHNIQUES

Two techniques were investigated in an attempt to reduce the noise generated by the USB system. The first was acoustic treatment on the flap upper surface and/or trailing edge and the second was by blowing through a slot close to the flap trailing edge.

4.4.1 Acoustic Treatment

Fourteen noise suppression treatments, defined in Figure 4-69, were investigated using three acoustic materials and three basic configurations. The materials were two perforated and one fibermetal sheets. They were used to replace the top surface of the flap, either the whole surface or only the rear half, and as trailing edge extensions. In addition, one configuration used streamwise splitters at the flap trailing edge.

An initial evaluation of the configurations is shown in Figure 4-70, where the change in OASPL relative to the baseline hard-surface flap is plotted against microphone position for the flyover and 30° elevation planes. The results can be grouped into the following categories:

- a) Configurations with the complete upper flap surface treated generally show a small reduction in flyover noise and a small increase in sideline noise.
- b) Configurations with half of the surface treated show an increase in both flyover and sideline noise.

- c) Configurations with porous trailing edge extensions produce a reduction in both flyover and sideline noise.
- d) Configurations with the complete upper surface treated and the trailing edge extension produce a substantial decrease in flyover noise but no significant change at the sideline.
- e) Configurations with half the upper surface treated and the porous trailing edge extension show no significant change in either flyover or sideline noise.
- f) The configuration with the streamwise trailing edge splitters had no significant effect.

One-third octave band spectra for all the configurations are compared with the baseline in Figures 4-71 through 4-84. The spectra shown are for two microphone positions in the flyover plane. Configurations 2 through 4, which have the whole upper surface treated, show a significant reduction in SPL at low frequencies (200-1000 Hz) at the 60° microphone position but very little change at the 120° position. The configurations with half the surface treated (5 through 7) all show a small increase in mid-frequency noise for both microphone positions. Configurations employing a porous trailing edge extension are shown in Figures 4-77 through 4-81. Those with a 2.54-cm extension (8, 9, and 10) show a well-defined reduction in SPL between 400 and 2000 Hz for the forward microphone position but only a slight reduction over the whole spectrum at the aft position. When the shorter

1.52-cm extension was applied (Figures 4-80 and 4-81), the reduction in SPL occurred over a broader frequency range (400 to 5000 Hz) and at both the forward and aft microphone locations.

Configuration 13 combines the upper surface treatment of configuration 4 with the trailing edge extension of configuration 10. Examination of the spectra of Figure 4-82 shows an almost identical result to that obtained for configuration 4 (Figure 4-73), indicating that the addition of the porous trailing edge produced no additional benefit over that obtained with the upper surface treatment. Configuration 14, however, which combines configurations 7 and 10, shows a greater noise reduction at the forward location than either of the treatments separately. The final configuration tested (number 15) was different from the others in that porous treatment was not used. Instead, a row of streamwise splitters was arranged along the flap trailing edge to change the trailing edge wake characteristics. The effect of these splitters on the acoustic spectrum is shown in Figure 4-84. At the forward microphone location there is a small reduction in SPL throughout the spectrum whereas at the aft position there is no significant change.

4.4.2 Trailing Edge Blowing

The effect of flap trailing edge blowing was investigated on the large-scale outdoor rig using a 30° flap model and an aspect ratio 8 nozzle. The wing chord was 60.96 cm and the blowing slot was 5.5 cm upstream of the trailing edge on the flap upper surface. Details of the model are shown in Reference 1. The effects of three parameters were investigated during the study: slot height, slot exit velocity, and USB nozzle exit velocity.

4.4.2.1 Effect of Slot Height - Three slot heights were tested: 0 (sealed), 0.254 cm, and 0.508 cm. Results are shown in Figures 4-85 through 4-88. The

OASPL directivity plots show a reduction in noise level as the slot height is increased for all microphone positions and for both USB jet velocities tested. Spectral plots show some noise reduction throughout the entire spectrum although the effect seems to be greater at high frequencies. Forward microphone positions also show a greater reduction than aft in both the flyover and 30° elevation plane.

4.4.2.2 Effect of Slot Exit Velocity - The effect of varying this parameter with a fixed USB nozzle velocity is shown in Figures 4-89 through 4-94. The directivity plots in Figures 4-89 and 4-90 show a progressive decrease in noise levels at all microphone locations as the slot velocity is increased up to a certain point, and then the noise begins to increase again. The larger slot gives greater noise reductions. Spectra are plotted for two microphone positions, two slot heights, and two USB jet velocities in Figures 4-91 through 4-94. The trends are similar in all of these plots. Up to a point, as the slot velocity is increased, the mid- and high-frequency sound pressure levels are reduced but the low frequencies are unaffected. As the slot velocity is increased still further, the high-frequency end of the spectrum begins to rise again as the noise from the slot jet itself becomes dominant in this frequency range.

The results of this investigation are summarized in Figure 4-95, where change in OASPL is plotted against the ratio of the slot and USB velocities. As the velocity ratio is increased, there is an initial small increase in noise and then a rapid decrease, with the minimum occurring at a velocity ratio of 0.7 for the large slot and 0.8 for the small one. After this minimum the levels begin to rise again and are still rising at the maximum ratio of 1.0 that was tested. Flyover and sideline results are similar,

with the larger slot producing significantly greater noise reductions in both cases.

4.5 NEARFIELD NOISE

Three series of tests were carried out to measure nearfield noise. The first was conducted statically in the anechoic wind tunnel and used an array of microphones mounted adjacent to the jet on the small-scale rig. The second measured fluctuating surface pressures with Kulite transducers mounted on the flap surface of the large-scale outdoor rig. The third again used the small-scale anechoic wind tunnel rig and measured sound pressure levels on a simulated fuselage surface with flush-mounted 0.32-cm diameter microphones.

4.5.1 Small-Scale Nearfield Data

Nearfield noise data were taken with an array of microphones adjacent to the small-scale rig as shown in Figure 4-96. The acoustic data were recorded on magnetic tape simultaneously with a farfield microphone 2.44 m forward of the flap on a normal to the flap upper surface. Nearfield/farfield cross-correlations were generated by playing the tape back through a B&K correlator, with the results shown in Figure 4-97. OASPL correlations are shown for the nine nearfield positions to help identify the source of the farfield noise. It is seen that the correlating parameter peaks on the centerline at the position closest to the trailing edge and decreases progressively downstream. It also drops off spanwise at the trailing edge but remains fairly constant across the span at positions further downstream. Some narrow-band cross-correlations were also attempted, but the only frequency at which correlation occurred was 500 Hz.

4.5.2 Wing Surface Fluctuating Pressures

The fluctuating pressures on the surface of the 60° flap were measured with four Kulite transducers on the large-scale outdoor rig. Their locations are defined in Section 2.2.3.2. The transducer in position 2, on the centerline just aft of the curved portion of the flap, failed early in the test, so data are available for only three positions. The data are plotted in one-third octave band form in Figures 4-98 through 4-101. A zero-velocity curve, representing instrumentation noise, is shown on each curve for reference. It is apparent that instrumentation noise does not affect the data at frequencies below 10 kHz.

Figure 4-99 shows the effect of jet velocity on the fluctuating surface pressures at two transducers for the AR-4 nozzle. At the position forward of the flap knee increasing the velocity initially increases the high-frequency SPL, whereas at the trailing edge the whole spectrum rises fairly uniformly. The data for the AR-8 nozzle show similar trends except that the low-frequency increase with the AR-4 nozzle could be caused by a partial flow separation.

Throughout the test program, on both the small- and large-scale rigs, there were instances where audible pure tones were generated by the model over a very narrow velocity range. These pure tones have been attributed to aeroacoustic feedback loops within the flowfield but the exact method of generation is not yet understood. As an aid to understanding this phenomenon, one of these pure tone conditions was set up with the Kulite transducers in position. The results are shown in Figure 4-100. It is apparent that the tone is generated in the vicinity of the nozzle, since the transducer in position 1 is the only one to pick up the strong tone at 1250 Hz.

The effect of nozzle impingement angle on the fluctuating surface pressures was also investigated and the results for the transducer nearest to the nozzle are shown in Figure 4-101. There appears to be little effect at low frequencies but there is a trend for SPL to increase with nozzle angle at the high-frequency end of the spectrum.

4.5.3 Fuselage Surface Fluctuating Pressures

Three microphones were flush-mounted in a simulated fuselage wall close to the trailing edge of the flap in the anechoic wind tunnel. The microphone positions are defined in Section 2.3.3.1. The aft microphone failed early in the test so data are available for only two microphones. Data were taken both statically and with freestream velocity.

OASPL is plotted for a range of jet and freestream velocities in Figure 4-102 for both microphone positions. At zero and 31 m/s forward speed, increasing the jet velocity produces the expected increase in OASPL, but as forward speed increases, the whole curve rises and flattens out. This is what could be expected if the boundary layer noise increases above the radiated noise of the jet. Figure 4-103 shows the one-third octave band spectra for the 215 m/s jet velocity. Increasing the freestream velocity from zero to 31 m/s produces no appreciable change in the spectrum but further increases cause the spectrum to rise significantly, indicating that the boundary layer pressure fluctuations dominate the radiated noise from the jet. The spikes in the spectra at 1250 and 20,000 Hz are probably caused by mechanical vibration, since no change in frequency occurs with velocity change.

4.6 VECTORED THRUST CONFIGURATION

A limited investigation was carried out to determine the acoustic characteristics of vectored thrust configurations, i.e., USB configurations in which

the nacelle is mounted above the wing on a pylon, and the nozzle is vectored down onto the wing surface for the powered lift mode. Circular nozzles were used for this phase of the test, which was conducted on both the small-scale anechoic room model and the large-scale outdoor rig.

Results of the small-scale tests are compared with the baseline results in Figures 4-104 through 4-106 for 30° and 60° flap angles. The one-third octave band spectra show a slight increase in low-frequency noise and a substantial increase at the high end of the spectrum, but OASPL versus jet velocity plots show no significant change in velocity exponents. The directivity plots of Figure 4-106 show that OASPL increases more at aft than forward microphone positions for the 60° flap, but is consistent for all microphones in the 30° case. Spectra for the outdoor rig (Figure 4-107) show an SPL increase throughout the whole spectrum, with the difference tending to be larger at the low-frequency end. The directivities in Figure 4-108 show a greater increase in OASPL at aft locations for both flap settings. The 60° case is quieter than the baseline at forward locations.

4.7 BASELINE NOISE DIRECTIVITY

Much of the acoustic data presented in preceding sections deals with the effects of geometric variations. The usual baseline for the perturbations was the following configuration:

AR-4 Nozzle	$\delta = 30^\circ$	
$\theta_N = 20^\circ$	$R_c = 7.62 \text{ cm}$	(Small-scale model)
$X_N/C = 20\%$	$L_f = 21.76 \text{ cm}$	

The noise directivity characteristics of the baseline are described below.

4.7.1 OASPL Directivity

The OASPL directivity patterns obtained from the small-scale and large-scale test rigs are shown in polar form in Figures 4-109 through 4-112. The small-scale data show that above the wing the sound is radiated very uniformly, there being very little change with θ or ϕ until the horizontal plane ($\phi = 0$) is approached. Under the wing the levels increase progressively with ϕ but there is very little change with θ . The large-scale model data, shown in Figures 4-110 and 4-111, agree well with the data from the small-scale rig except near the flyover plane at forward locations, where the large-scale noise levels fall off faster than the small-scale.

4.7.2 Normalized Spectrum

To provide a concise input to the noise prediction computer program the small-scale baseline spectra at all microphone locations were collapsed to a single curve, Figure 4-113.

The ordinate of Figure 4-113 is the SPL at any microphone, corrected to the SPL at the 90,90 ($\phi = 90^\circ$, $\theta'' = 90^\circ$) microphone by the correction factors n and K , which are plotted against microphone location in Figures 4-114 and 4-115. The abscissa is $S_N \times F_S$, where $S_N = \frac{fL_f(1 + \frac{\delta f}{57.3})^{1/3}}{V_J}$ and F_S is the Strouhal number correction factor, which is plotted against microphone location in Figure 4-116.

Figure 4-113 was developed to collapse the data but can perhaps be better understood by considering the reverse process - re-creation of the spectrum at a selected microphone. To do this, F_s at the microphone is read from Figure 4-116; points on the abscissa are calculated for a series of frequencies; the ordinate at each point is read from the mean line through the data; correction factors n , $n_{90,90}$, K , and $K_{90,90}$ are read from Figures 4-114 and 4-115; and the SPL's at each frequency are calculated by applying the correction factors in the manner indicated in the ordinate scale of Figure 4-113.

4.8 COMPARISONS WITH OTHER DATA

The farfield acoustic data have been compared in Sections 4.2 and 4.7 and show good agreement. Other comparisons with existing data are discussed below.

4.8.1 Earlier Data from Large-Scale Rig

Two nozzles used in the large-scale test had been used in another program in 1974, reported in Reference 1. Spectra and OASPL directivities from the two programs are compared in Figures 4-117 and 4-118, with satisfactory agreement being shown.

4.8.2 Farfield Data from Other Sources

The farfield acoustic data from the large- and small-scale rigs in this program have been compared with data from four other sources with nozzle areas ranging from 20.4 cm^2 to $7,150 \text{ cm}^2$ (References 3 through 6). The two sets of data from the present program were from very similar models and showed good agreement, as has been noted; the model geometries of the other test programs, however, were somewhat varied, with flap angles

ranging from 40° to 70° and nozzle shapes ranging from circular to rectangular with aspect ratio 5. Thus it would not be reasonable to expect the data to agree exactly, although corrections have been made where possible. All data were scaled to a common nozzle size ($A_N = 114 \text{ cm}^2$), microphone distance ($R = 6.1 \text{ m}$), and jet velocity ($V_j = 215 \text{ m/s}$), using the expression:

$$\Delta \text{dB} = 10 \log \frac{A_N}{114} - 20 \log \frac{R}{6.1} + 75 \log \frac{V_j}{215}$$

Frequency was also shifted by the linear scale factor between the models. The resulting one-third octave band spectra are compared in Figure 4-119. The SPL's around the peak agree fairly closely, but there is considerable spread at the high-frequency end of the spectrum. OASPL's are plotted against jet velocity in Figure 4-120. The velocity exponents agree fairly well but the current data are consistently 1 to 2 dB lower.

4.8.3 Surface Pressure Fluctuations

The data obtained with the Kulite transducers on the flap surface of the large-scale model are compared with similar data from Reference 7 in Figure 4-121. No change in level was made for the different model scales, since it is felt that the amplitude of the pressure fluctuations depends on the jet velocity and not on the scale of the turbulence. The frequency, however, has been shifted according to the linear model scale, since this parameter determines the scale of the turbulence. The OASPL's show moderately good agreement, considering the differences in the models, but the spectra do not, there being a much faster fall-off at high frequencies with the current data. Also the peak frequencies do not agree too well, indicating that the scaling method used may not be correct.

PARAMETER	RANGE TESTED							
	SMALL-SCALE				LARGE-SCALE			
		BASELINE				BASELINE		
NOZZLE ASPECT RATIO	2	4	8			4	8	
NOZZLE AREA (CM ²)	10.13	20.26				113.8		
NOZZLE IMPINGEMENT ANGLE (DEG.)	10	20	30		10	20	30	
NOZZLE CHORDWISE POSITION (% CHORD)		20	35	50		20	35	50
NOZZLE VERTICAL POSITION (CM)		0	1.27	2.54		0		
FLOW PATH LENGTH (CM)	19.09	21.76	24.43			51.58		
FLAP ANGLE (DEGREES)		30	45	60		30	60	
FLAP RADIUS OF CURVATURE (CM)	5.08	7.62	10.16			18.05		
JET EXIT VELOCITY (M/SEC)	180	215	250	285	180	215	250	285
JET TEMPERATURE (°C)		AMBIENT	93			AMBIENT		

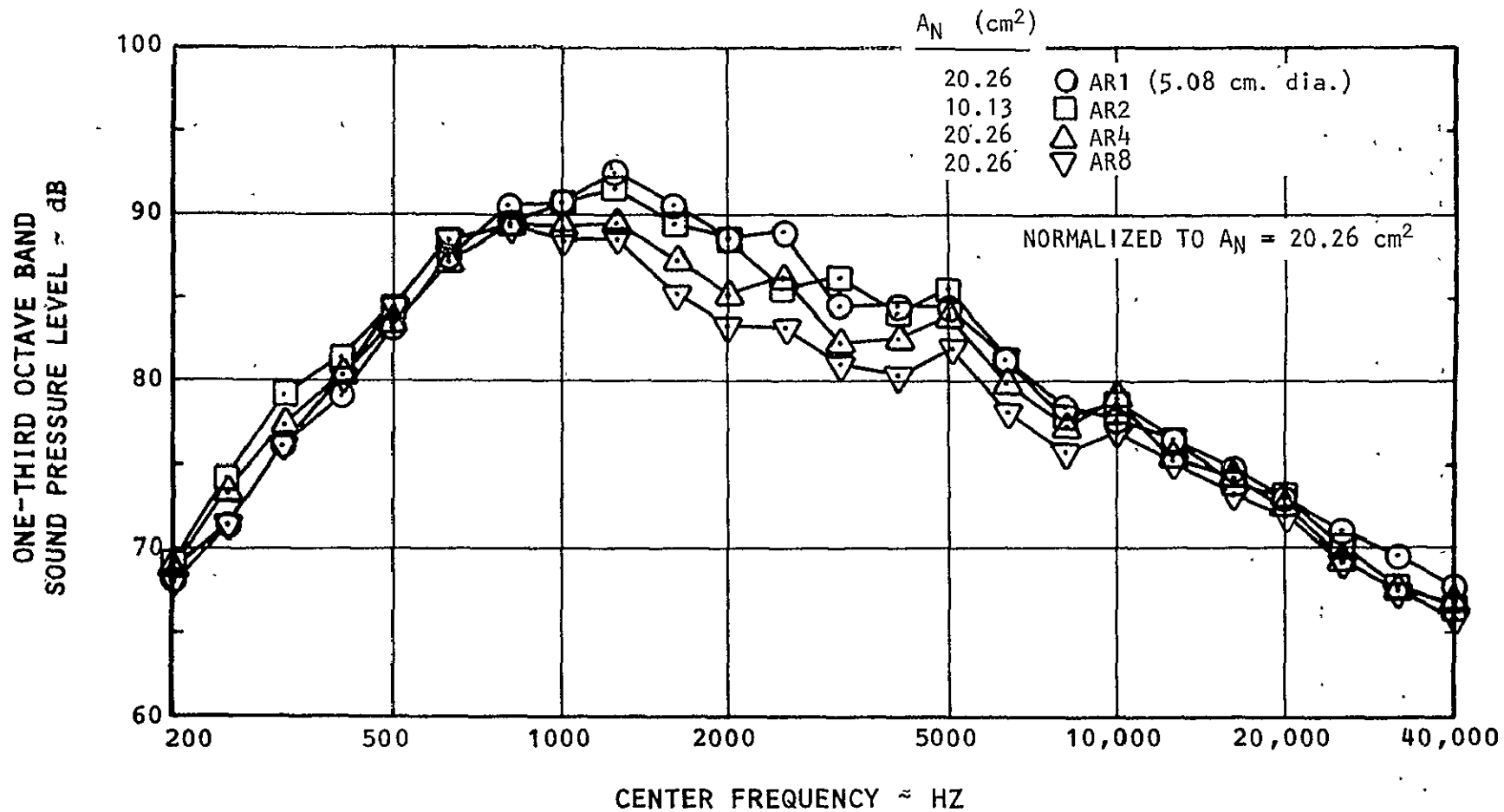
TABLE 4-1. BASELINE CONFIGURATIONS AND CONDITIONS AND PARAMETER RANGES

MODEL CONFIGURATION	PARAMETRIC VARIATION	BASILINE	FLAP ANGLE δ_f	NOZZLE CHORDWISE POSITION X	NOZZLE VERTICAL POSITION Z	NOZZLE IMPINGEMENT ANGLE θ_N	FLAP RADIUS OF CURVATURE R_C	FLOW PATH LENGTH L_f	JET TEMPERATURE	OVERWING NOISE	NOZZLE GEOMETRY
A)	<u>ANECHOIC ROOM</u>										
	AR2	X	X				X	X			
	AR4	X	X	X	X	X	X	X	X	X	
	AR8	X	X				X	X			
	2" d.	X	X		X	X	X	X			
	$\sqrt{2}$ " d	X									
	Ellipse	X	X								
	'D'	X	X								
	QCSEE	X	X								
B)	<u>OUTDOOR RIG</u>										
	AR4	X	X	X		X				X	
	AR8	X	X								
	QCSEE	X				X					X
C)	<u>ANECHOIC WIND TUNNEL</u>										
	AR2	X	X		X						

TABLE 4-2 MATRIX OF TEST DATA

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

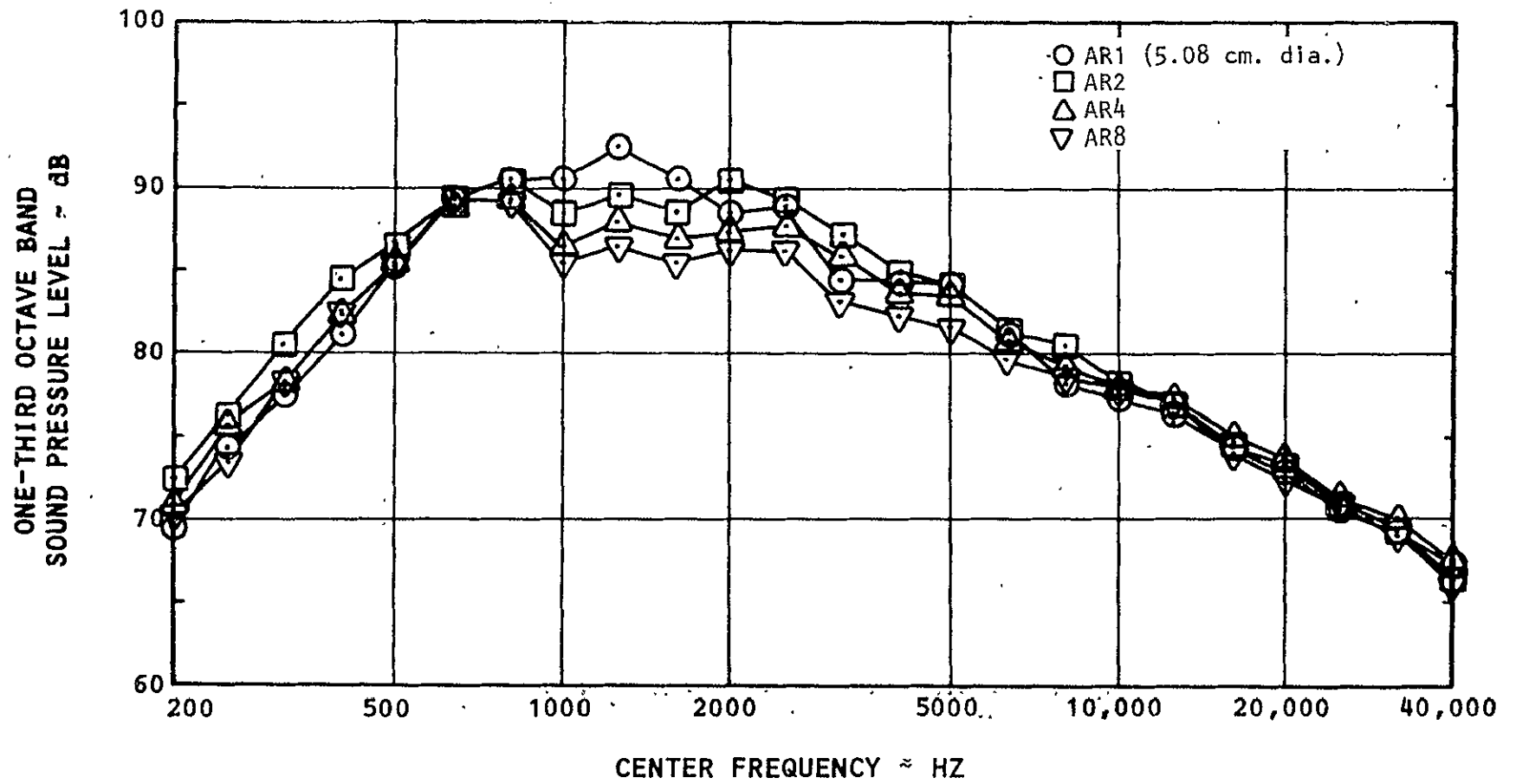
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-1. EFFECT OF NOZZLE ASPECT RATIO ON SPECTRUM

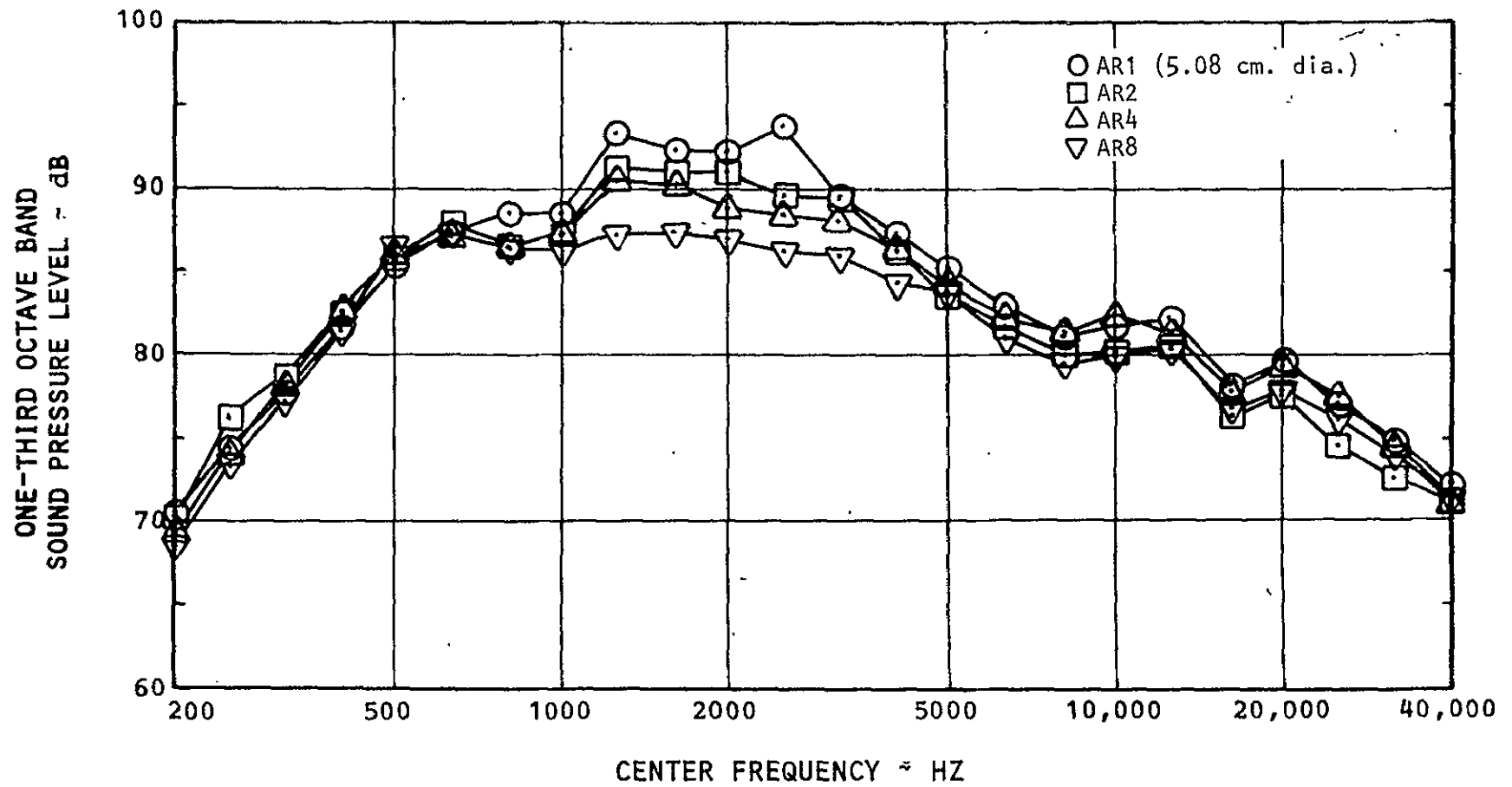
SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-1. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

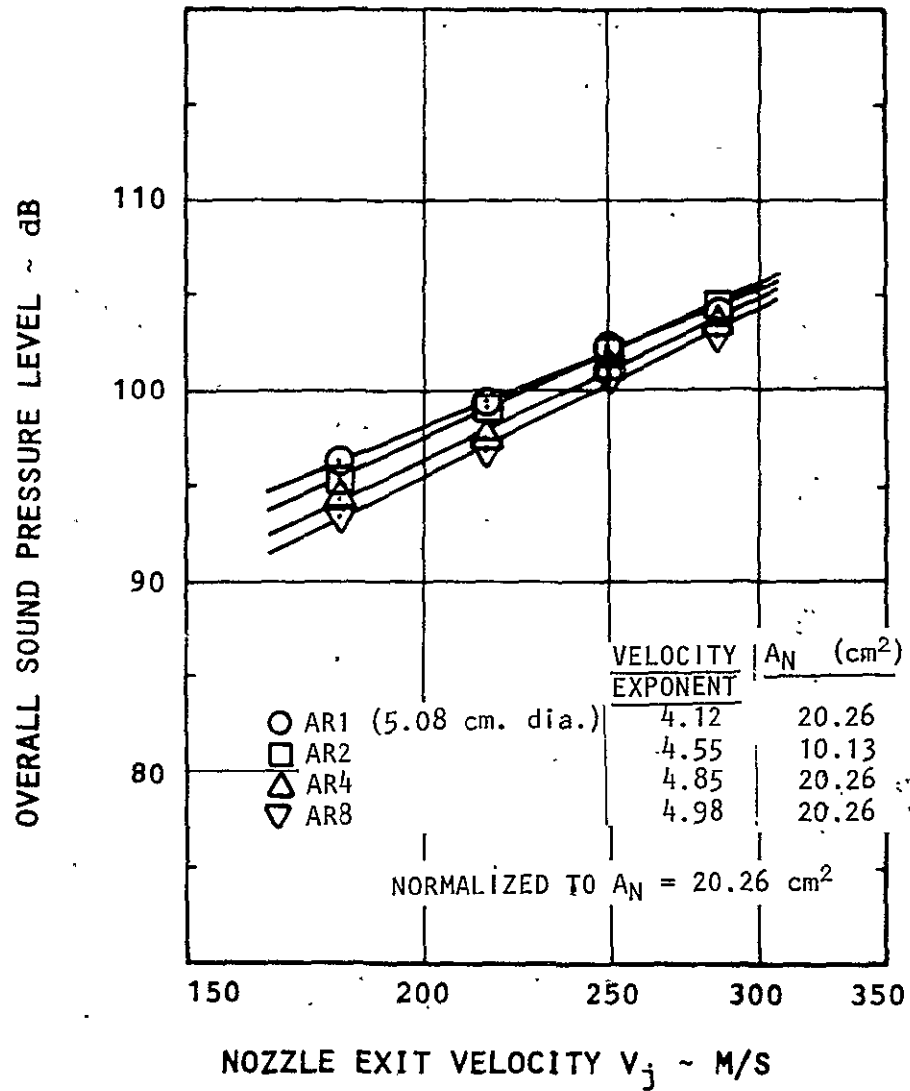


c) $\theta = 120^\circ$

FIGURE 4-1. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

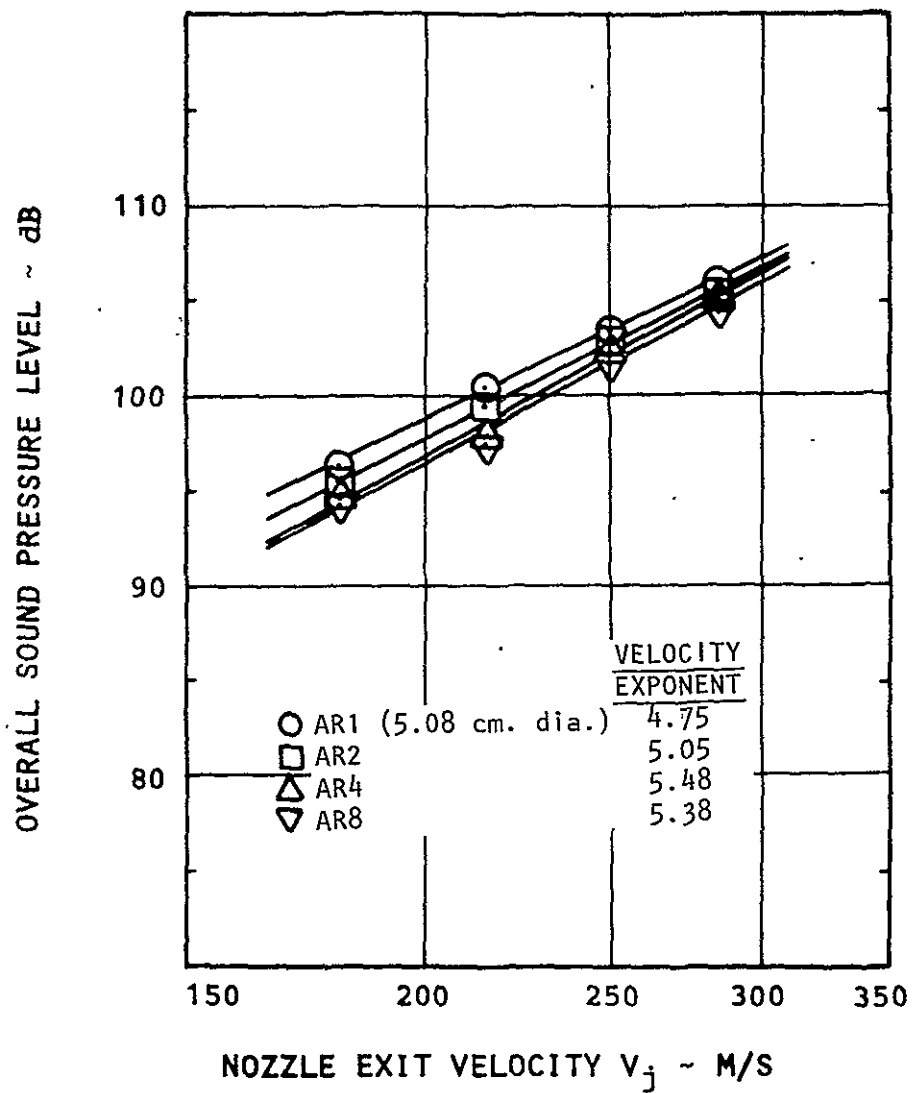
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-2. EFFECT OF NOZZLE ASPECT RATIO ON VELOCITY EXPONENT

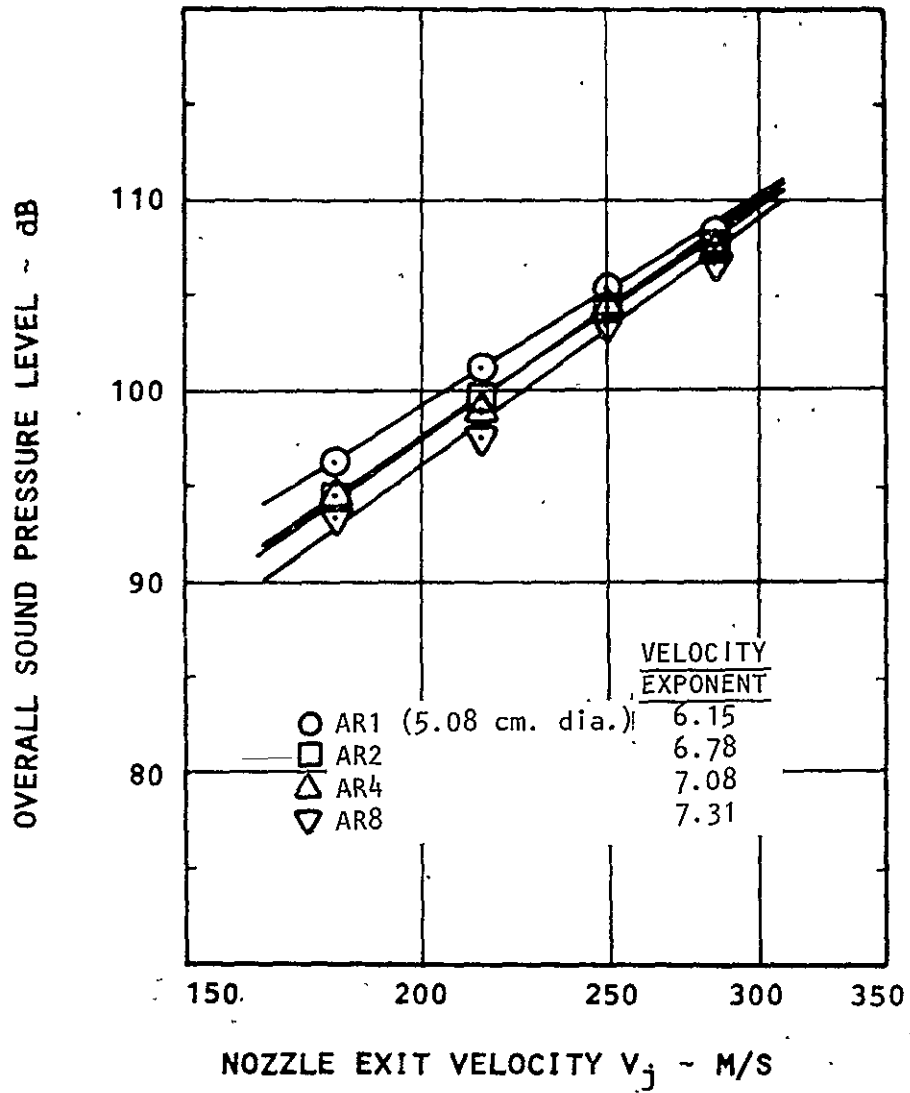
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-2. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-2. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

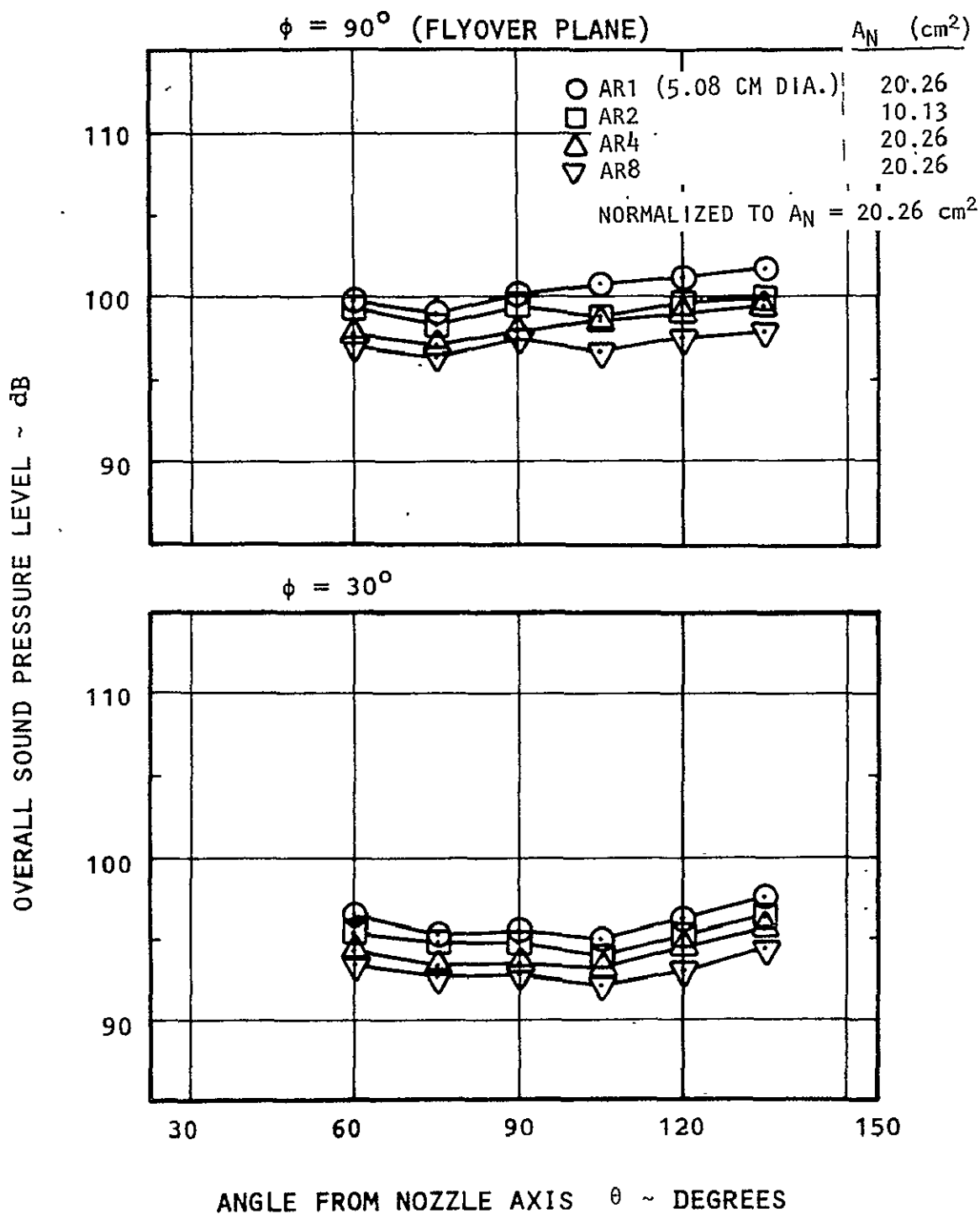
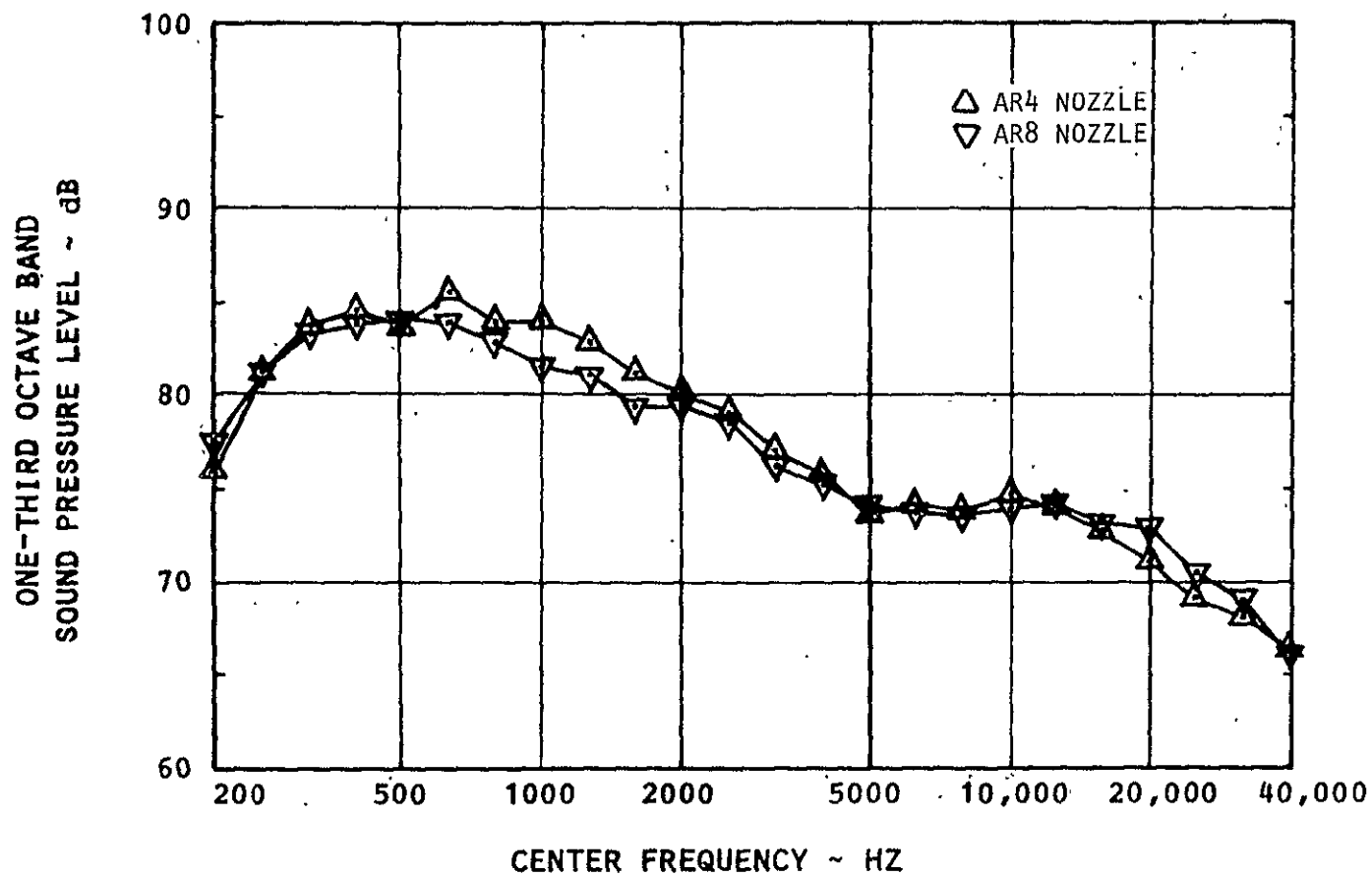


FIGURE 4-3. EFFECT OF NOZZLE ASPECT RATIO ON OASPL DIRECTIVITY

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

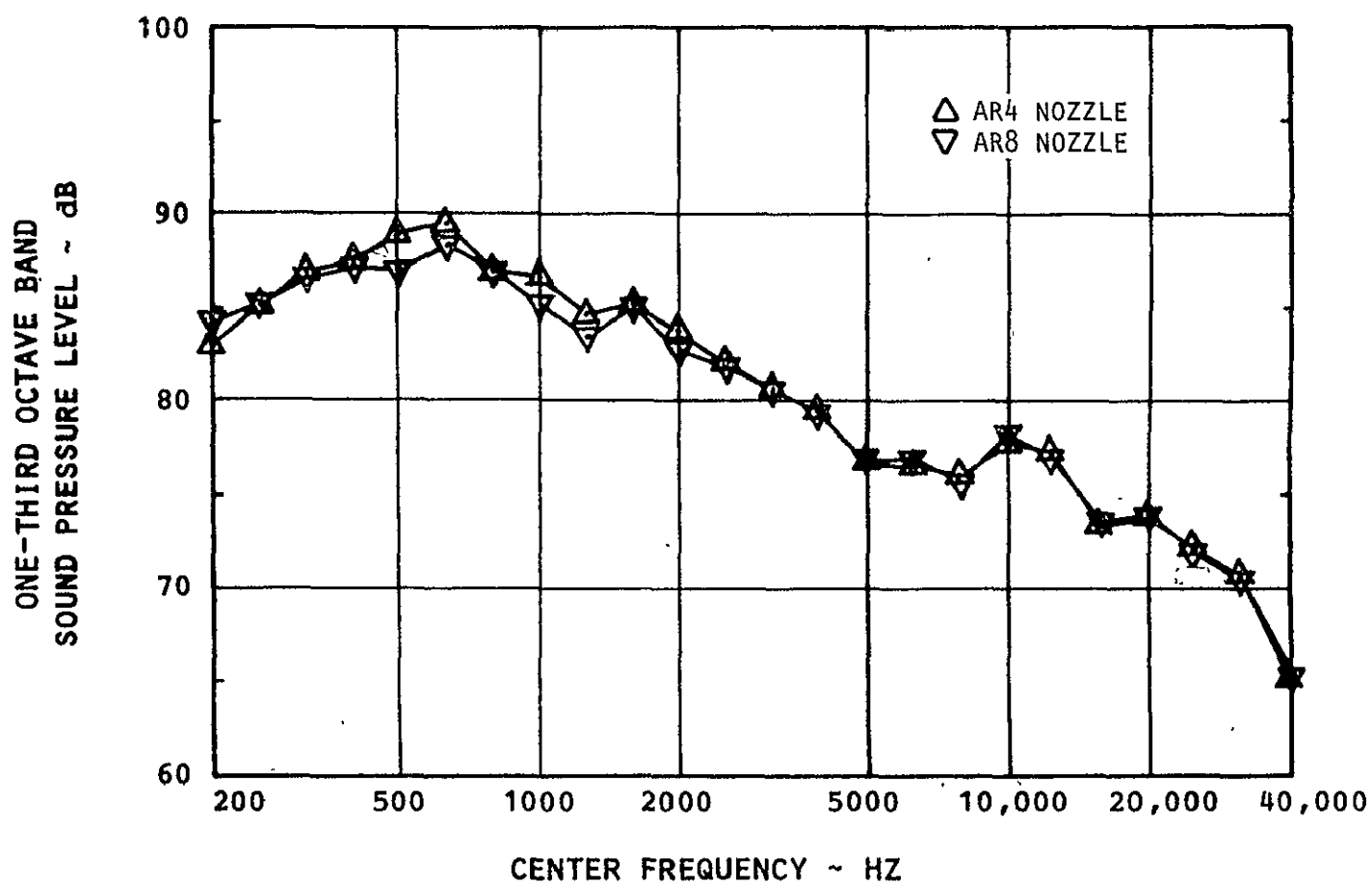
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-4. EFFECT OF NOZZLE ASPECT RATIO ON SPECTRUM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

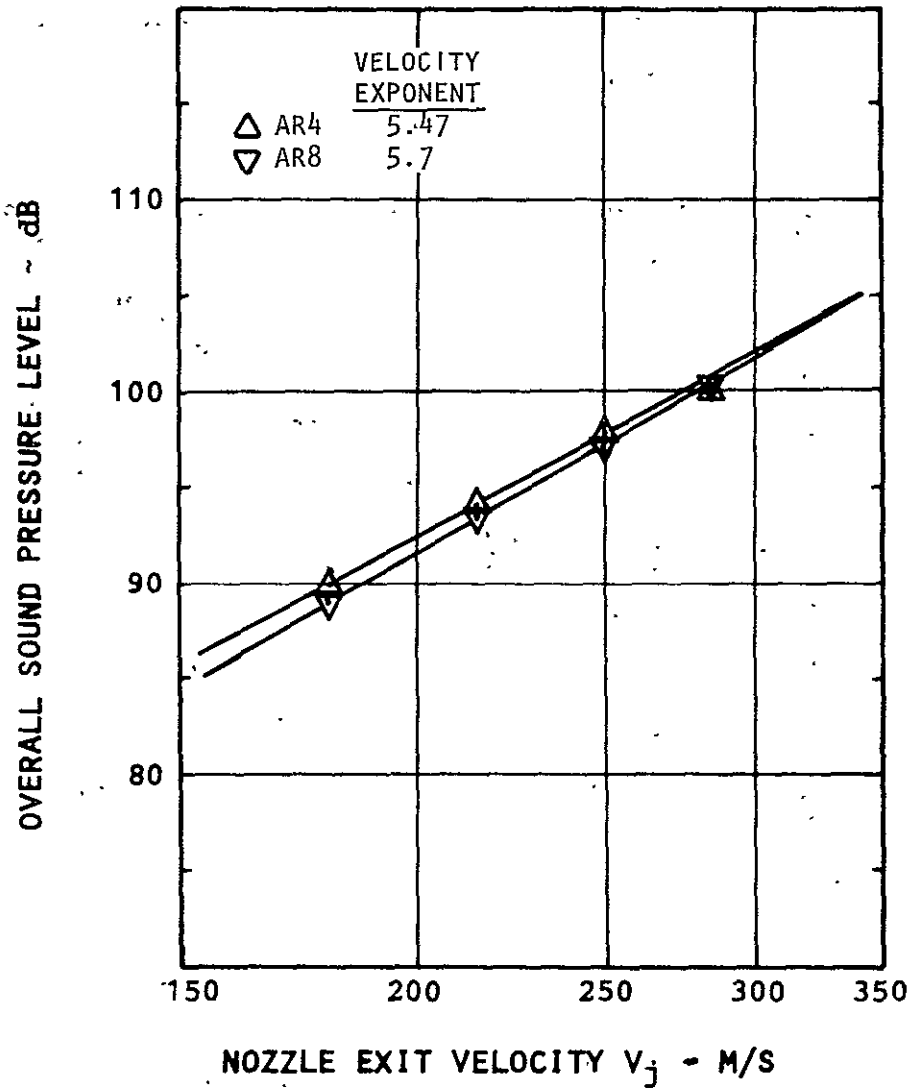


b) $\theta = 120^\circ$

FIGURE 4-4. (CONCLUDED)

LARGE-SCALE MODEL AT 6.1 METERS RADIUS

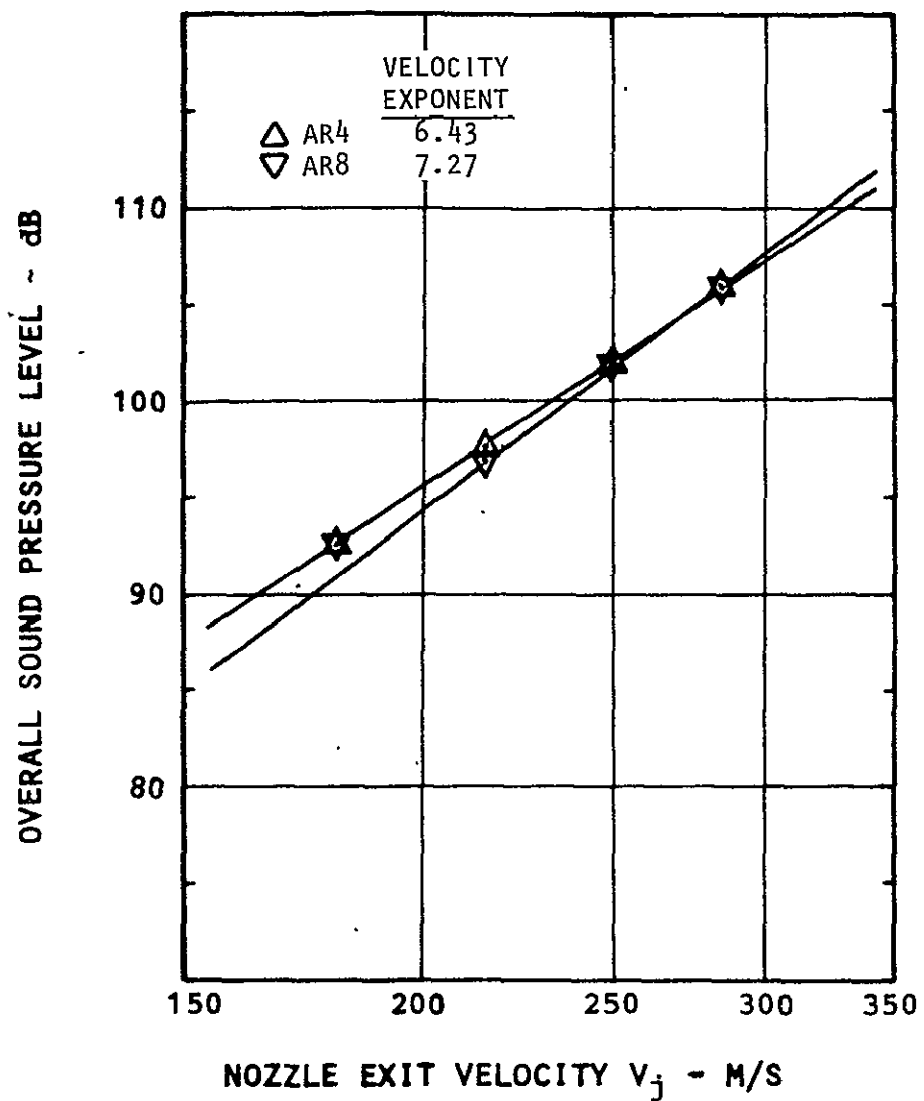
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-5. EFFECT OF NOZZLE ASPECT RATIO ON VELOCITY EXPONENT

LARGE-SCALE MODEL AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-5. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

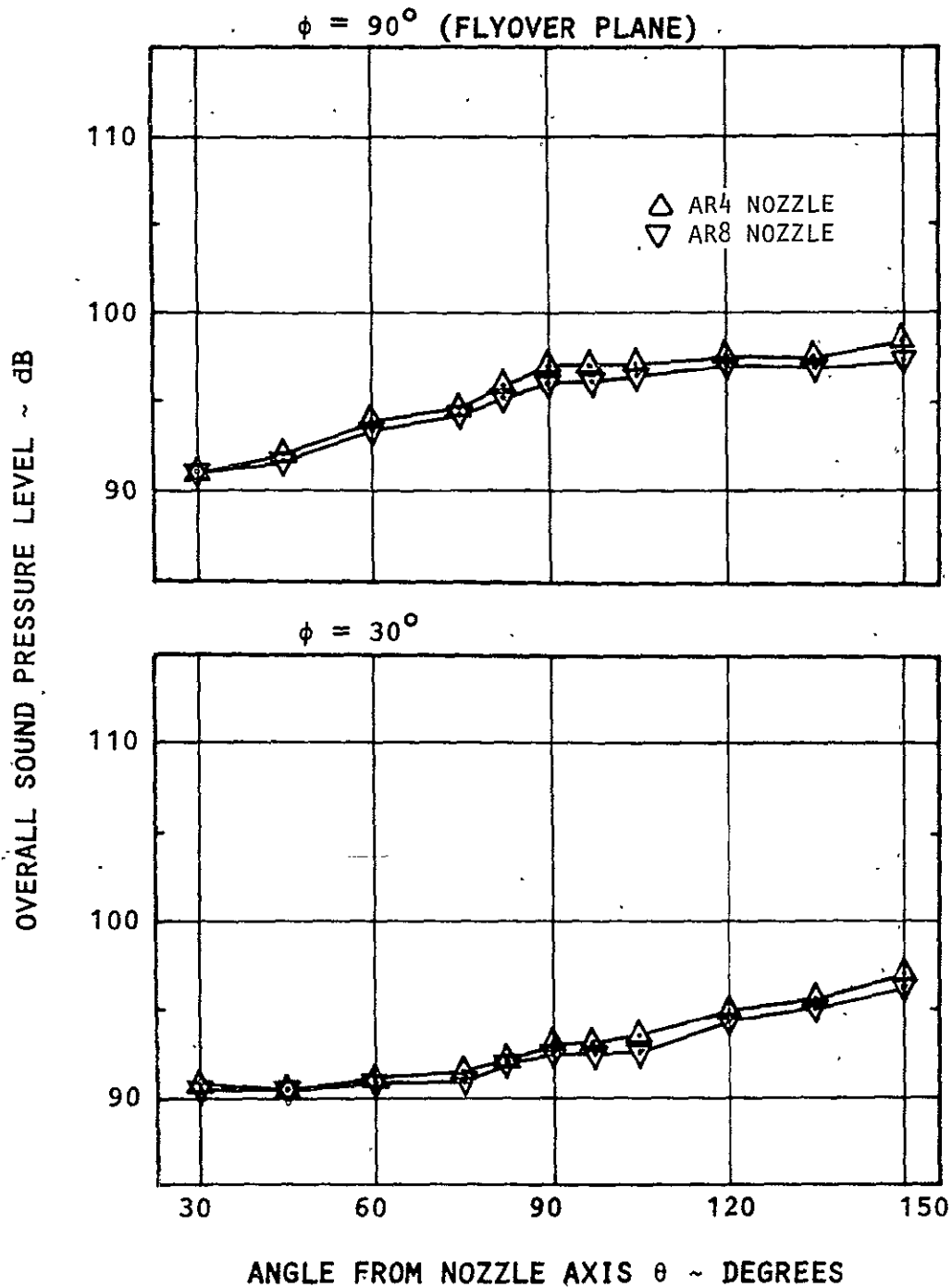
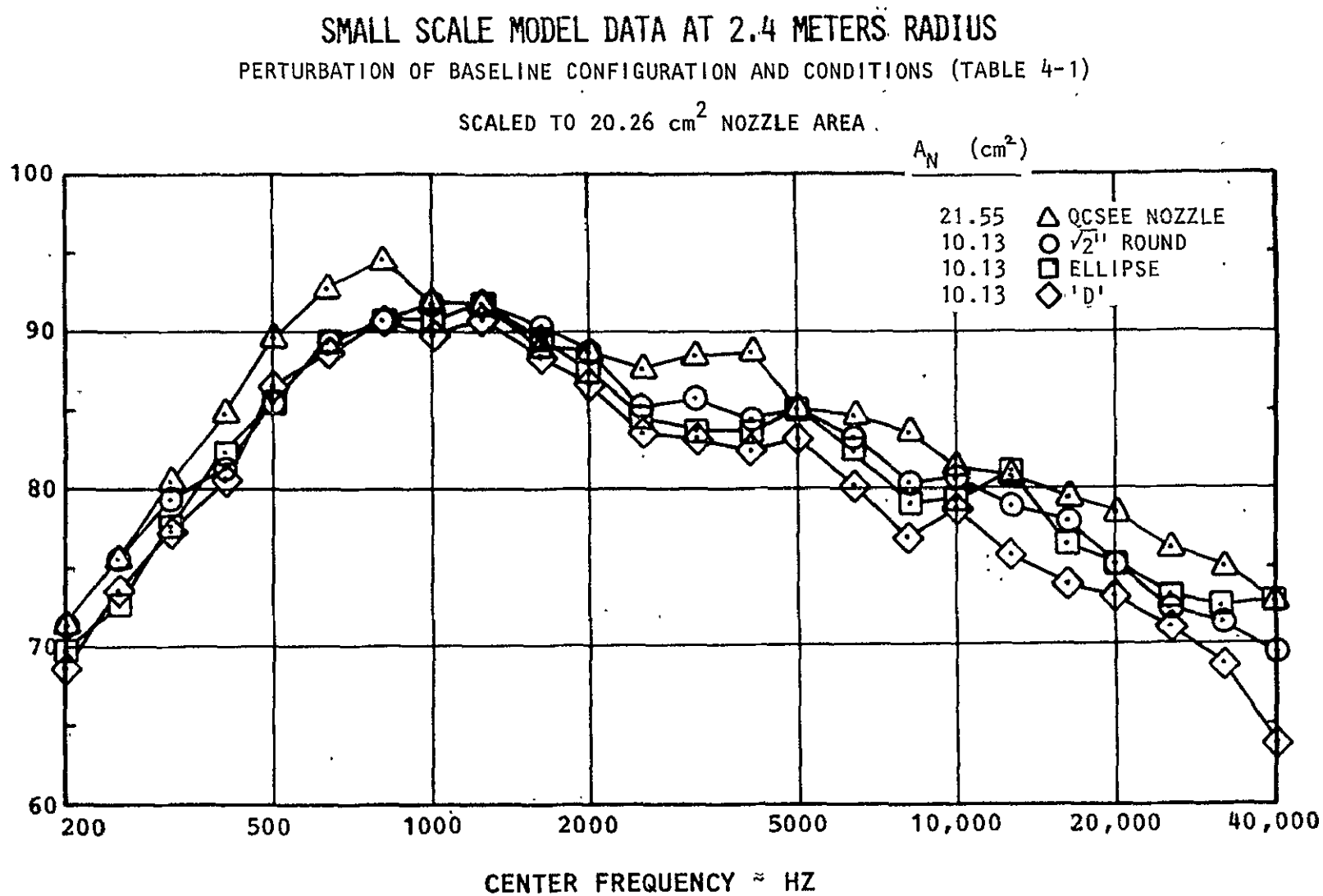


FIGURE 4-6. EFFECT OF NOZZLE ASPECT RATIO ON OASPL DIRECTIVITY

ONE-THIRD OCTAVE BAND
SOUND PRESSURE LEVEL - dB

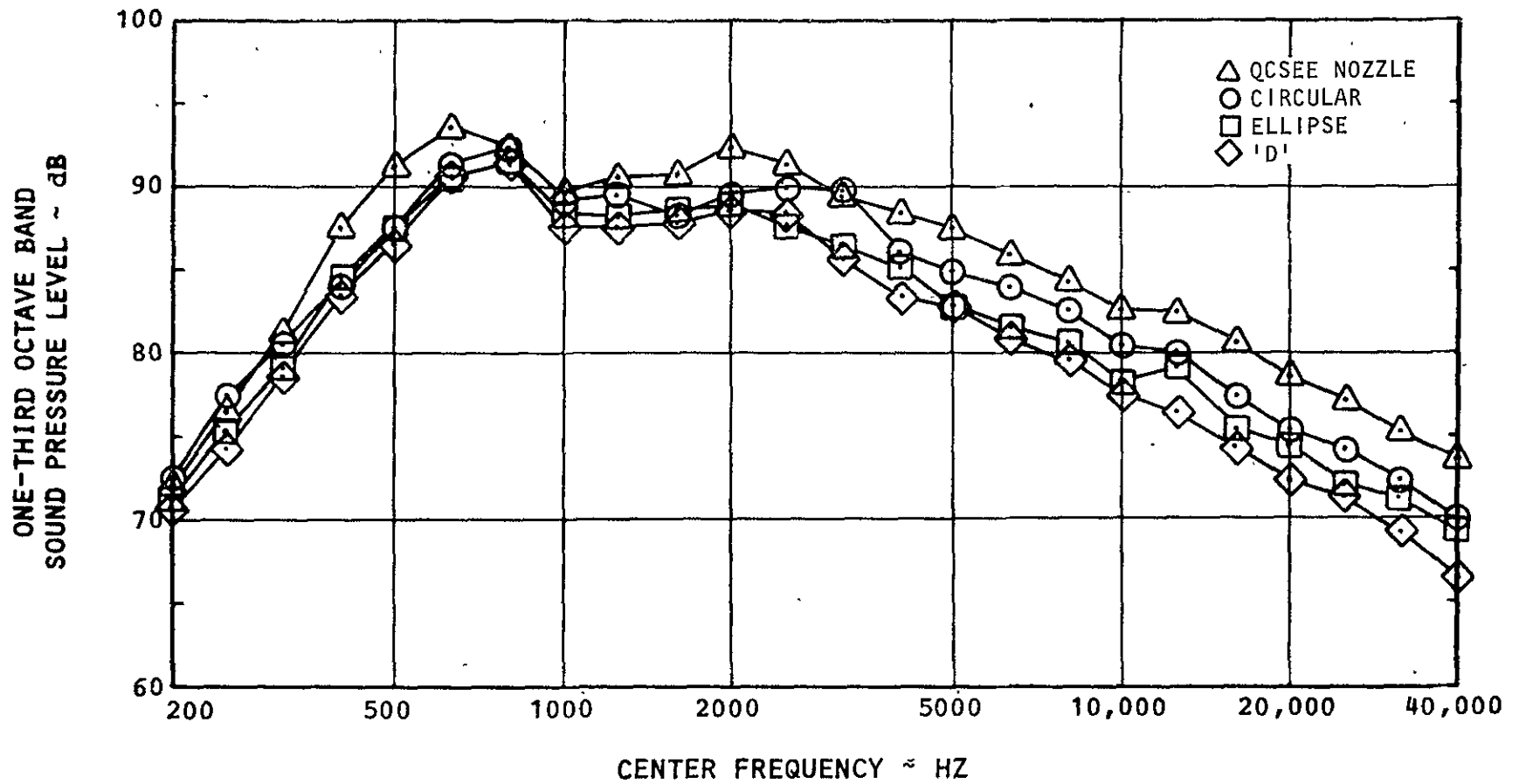


a) $\theta = 60^\circ$

FIGURE 4-7. EFFECT OF NOZZLE SHAPE ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

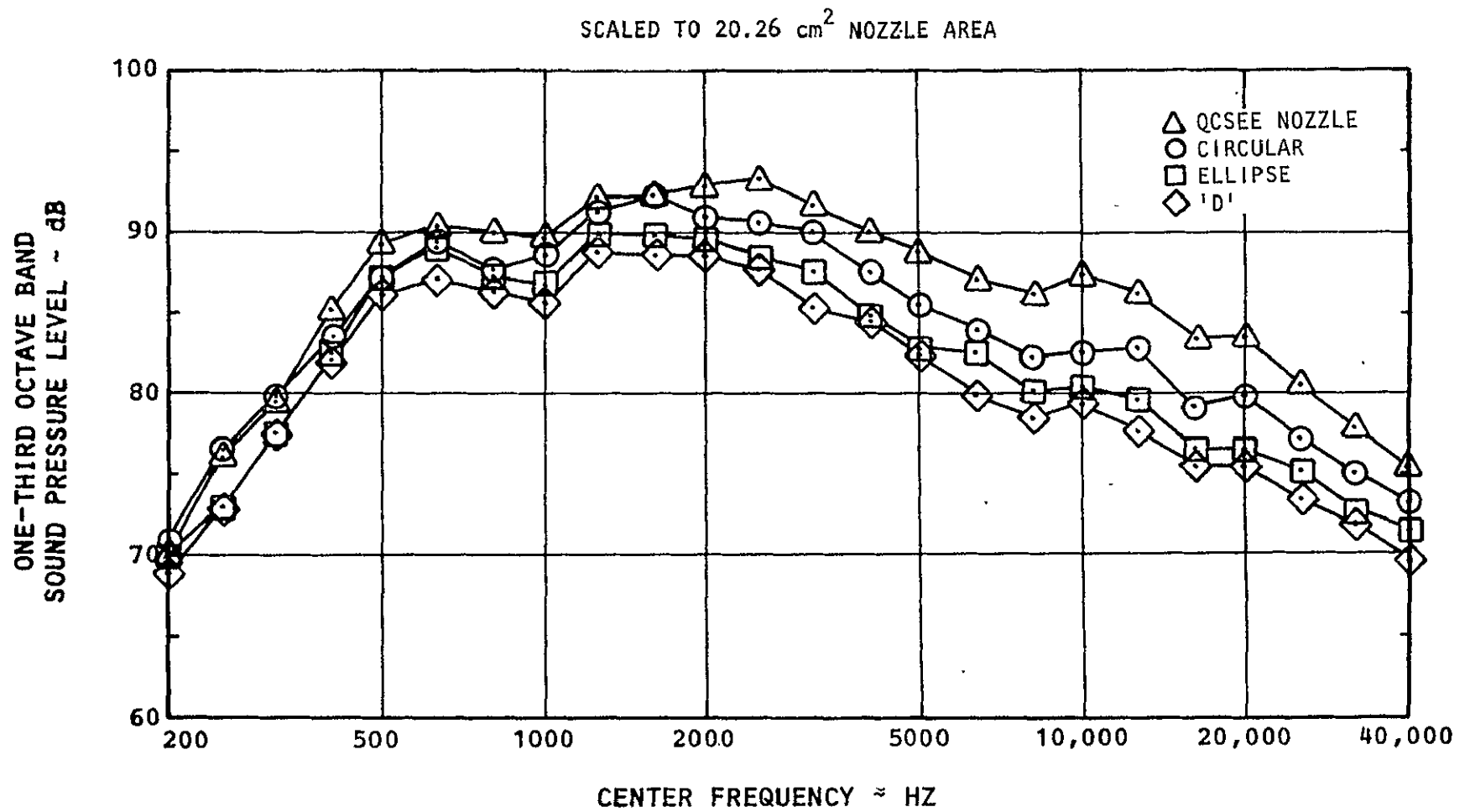
SCALED TO 20.26 cm² NOZZLE AREA



b) $\theta = 90^\circ$

FIGURE 4-7. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

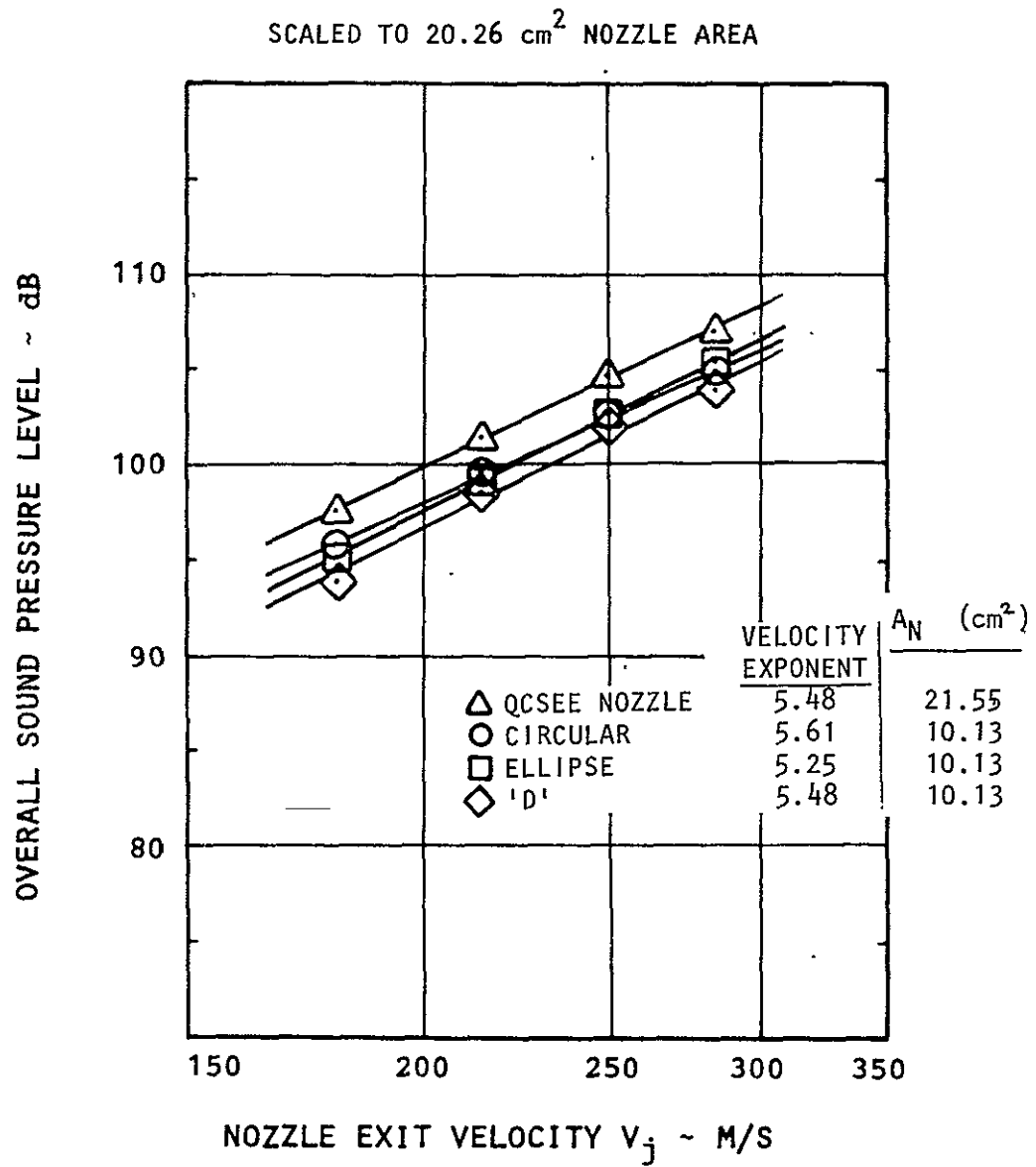


c) $\theta = 120^\circ$

FIGURE 4-7. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

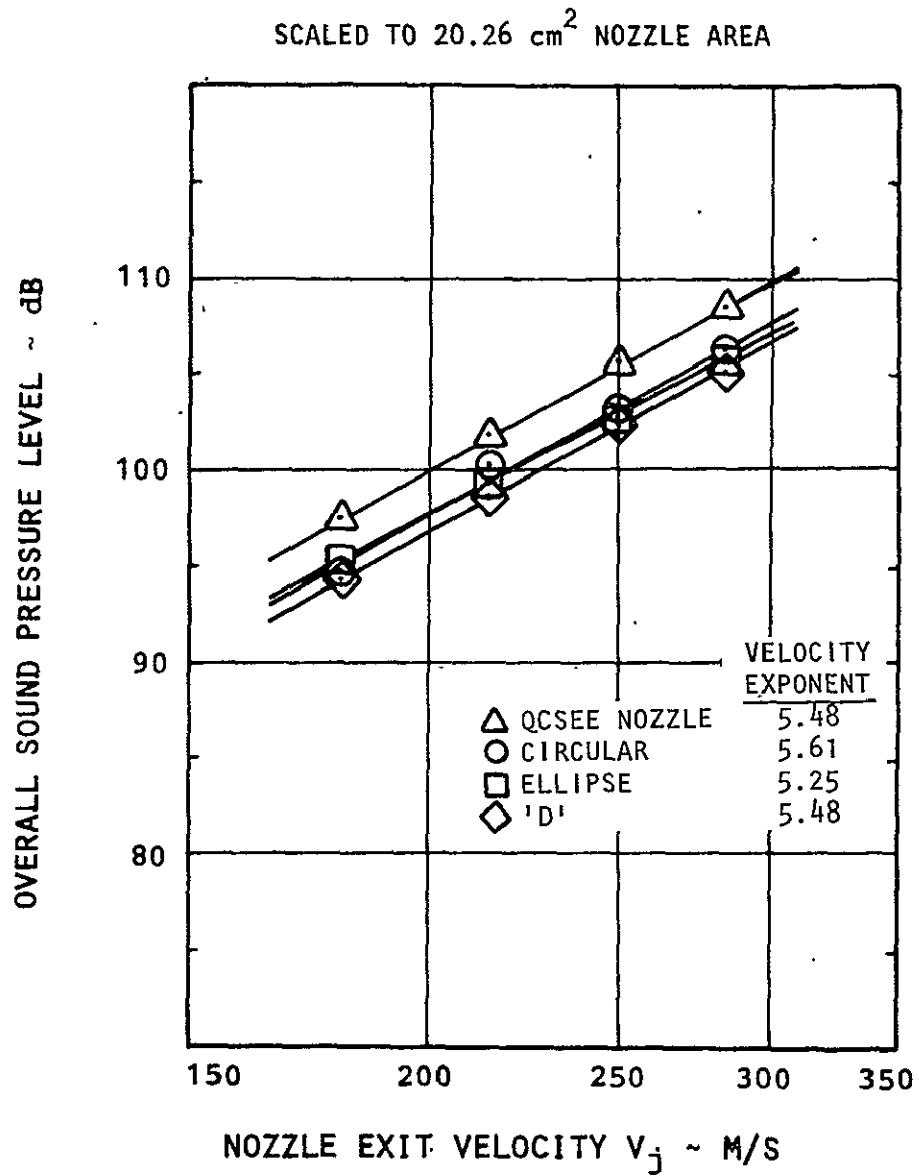
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-8. EFFECT OF NOZZLE SHAPE ON VELOCITY EXPONENT

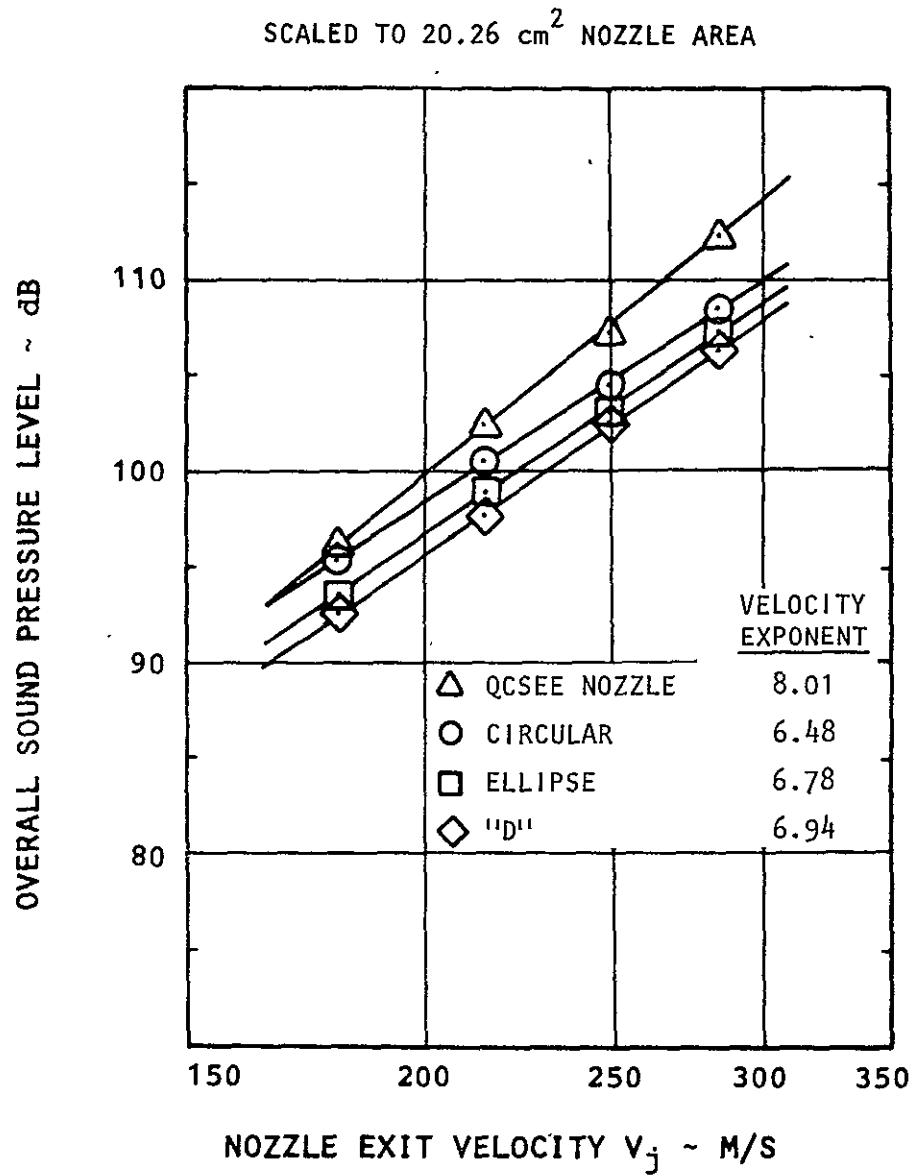
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-8. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-8. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)
 SCALED TO 20.26 cm² NOZZLE AREA

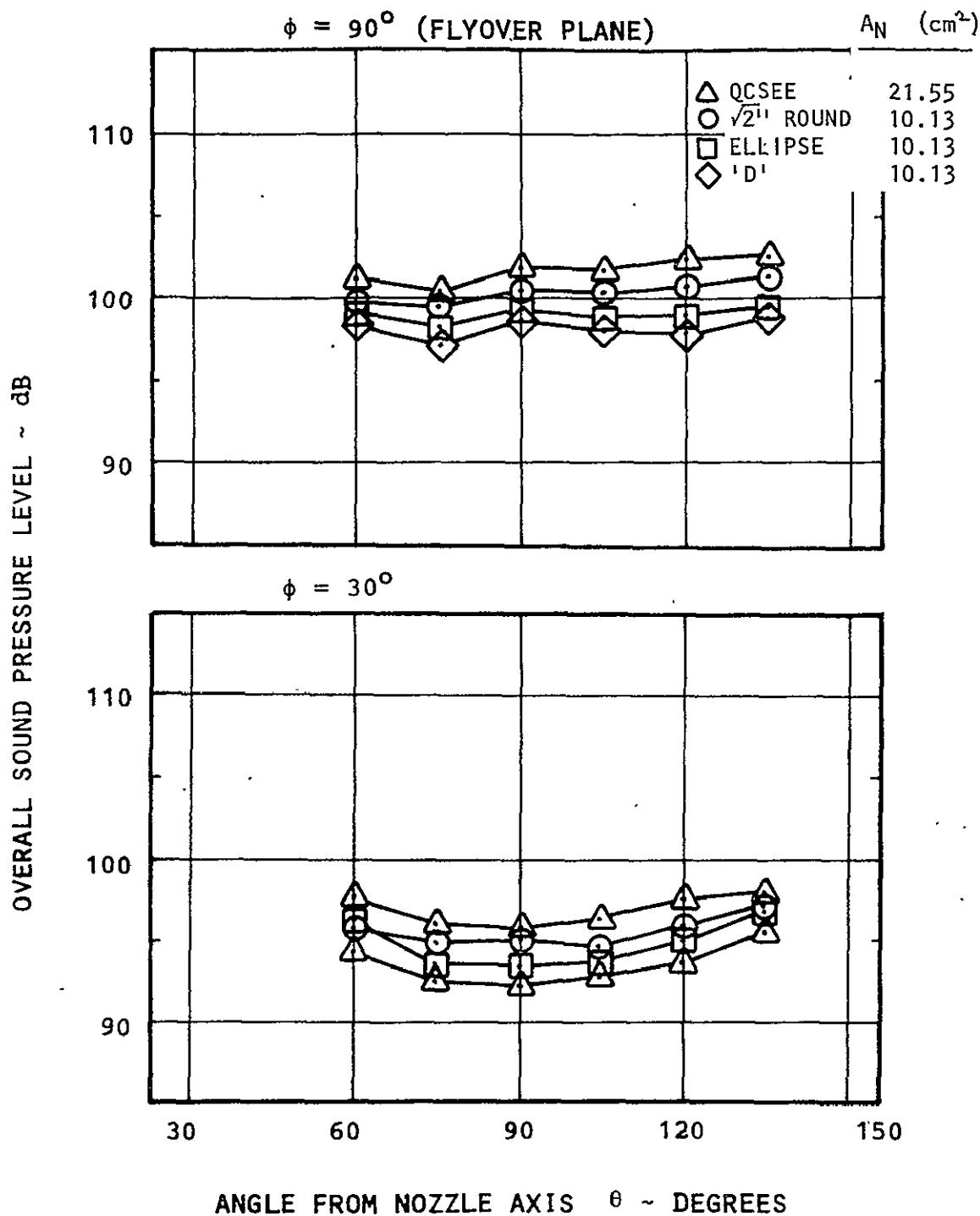
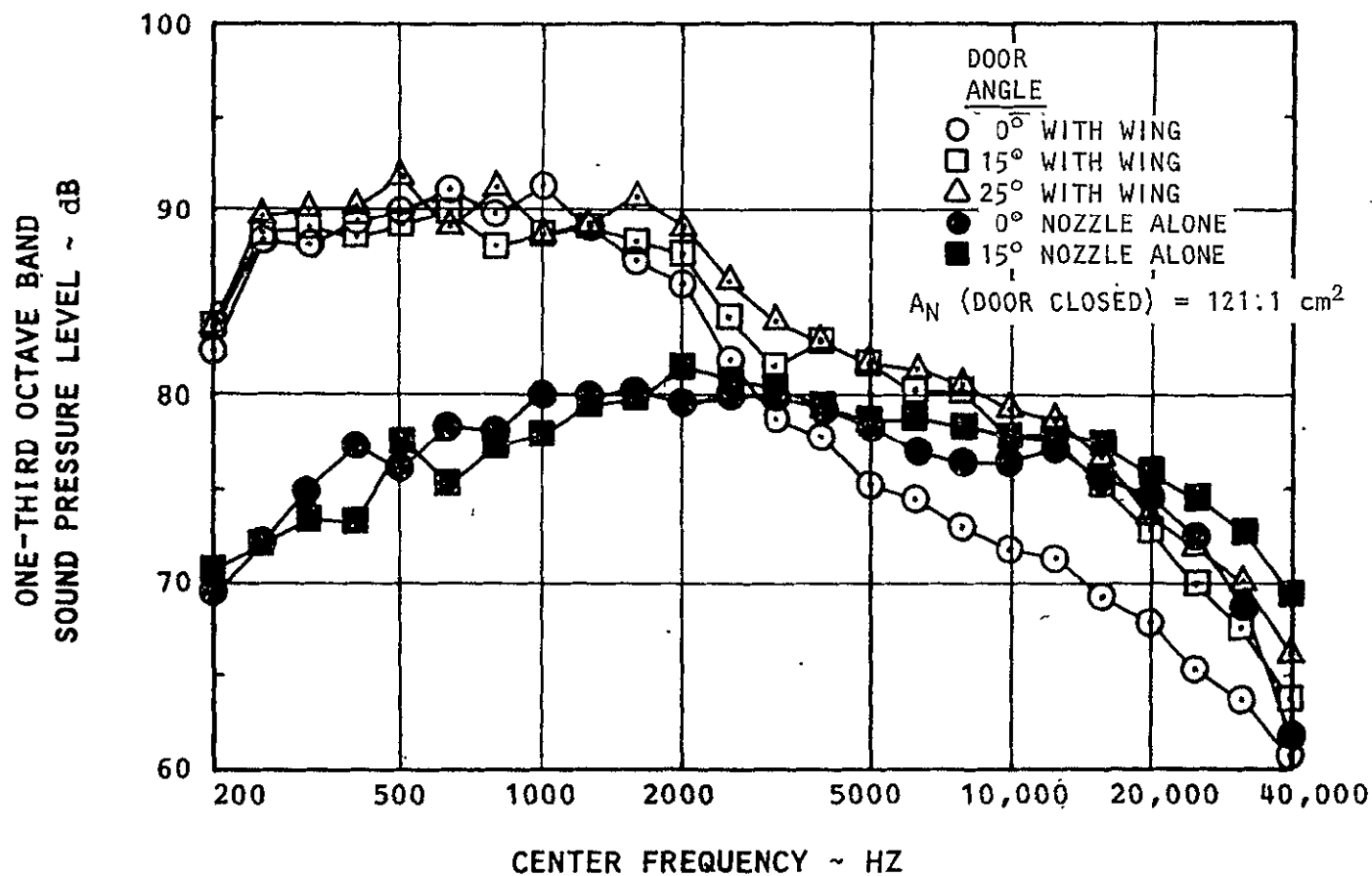


FIGURE 4-9. EFFECT OF NOZZLE SHAPE ON OASPL DIRECTIVITY

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-10. QSCEE NOZZLE - EFFECT OF DOOR ANGLE

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

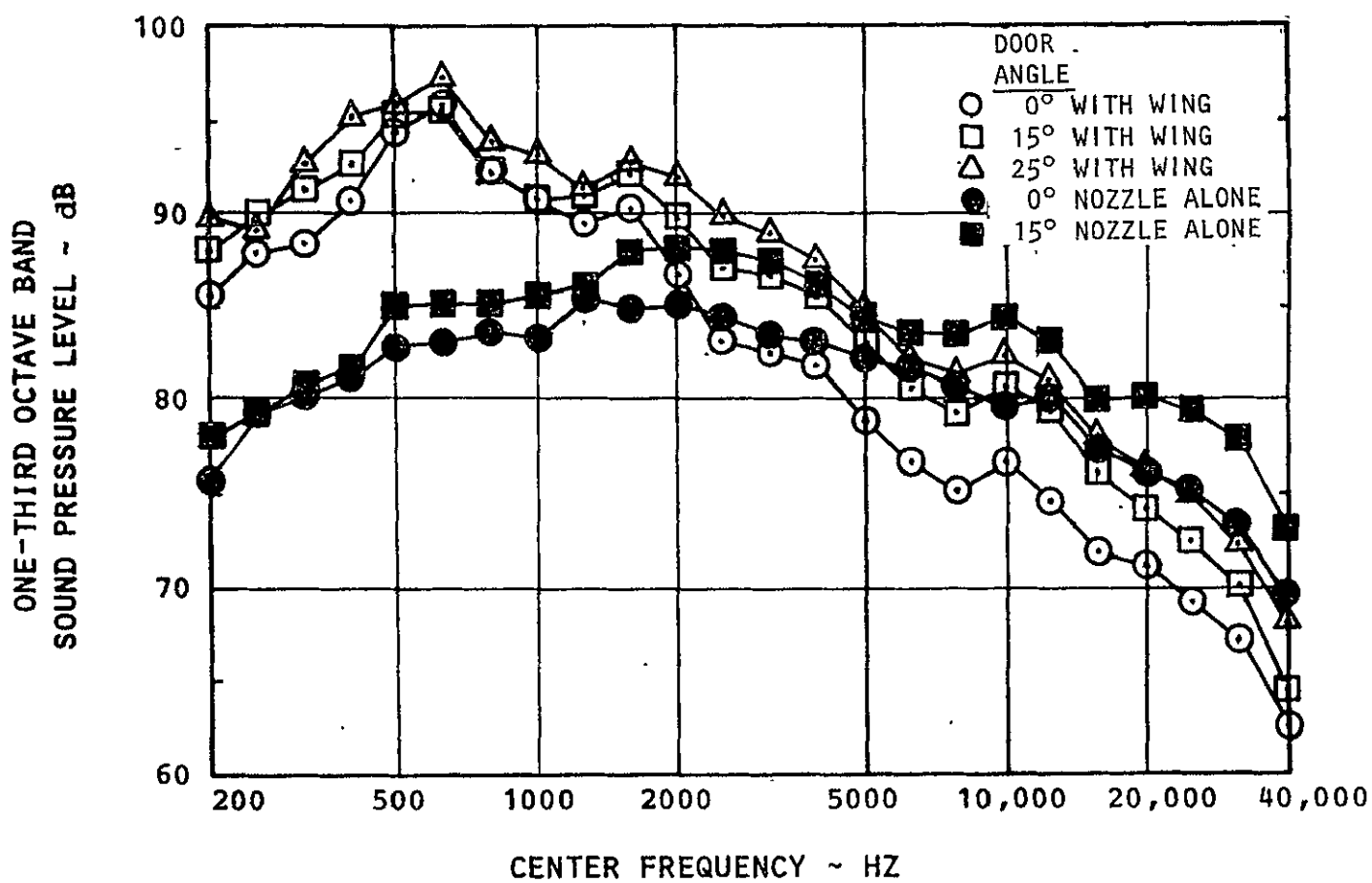
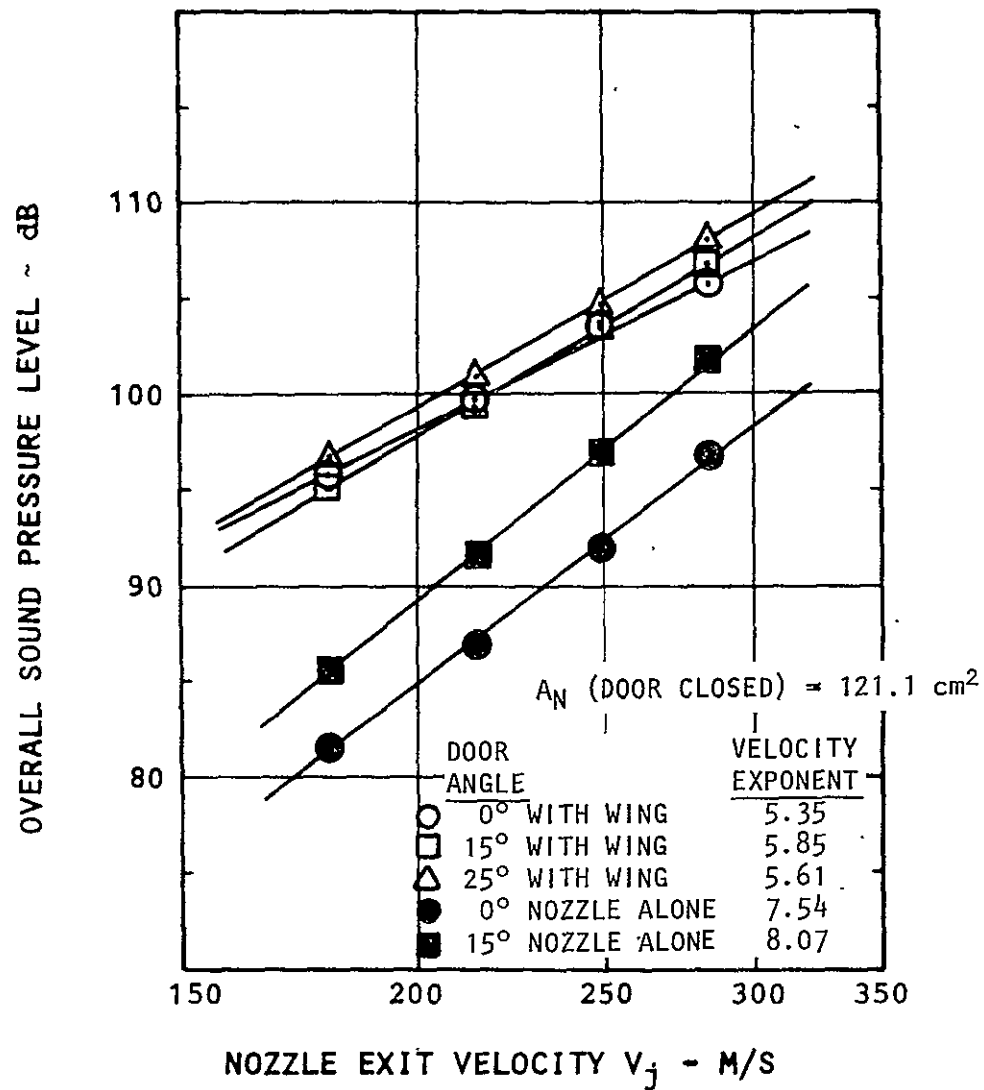
b) $\theta = 120^\circ$

FIGURE 4-10. (CONCLUDED)

LARGE-SCALE MODEL AT 6.1 METERS RADIUS

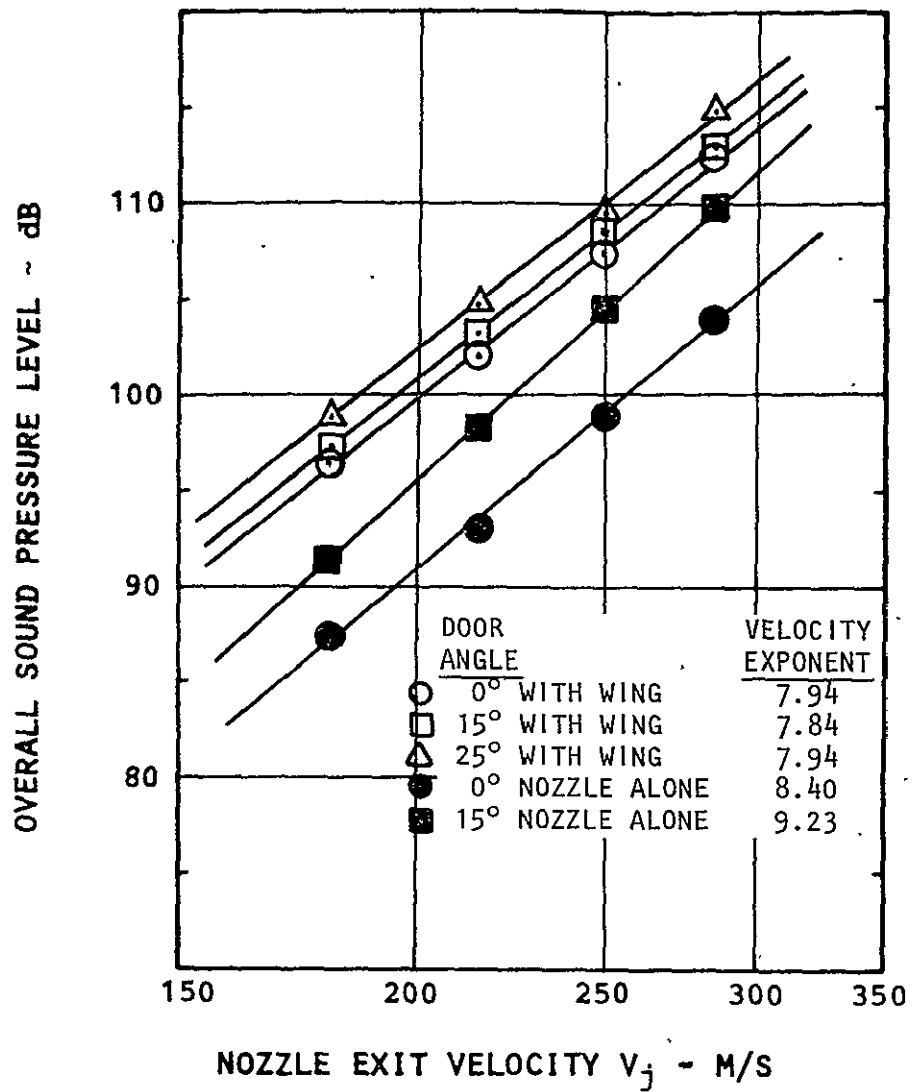
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-11. QCSEE NOZZLE - EFFECT OF DOOR ANGLE ON VELOCITY EXPONENT

LARGE-SCALE MODEL AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-11. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

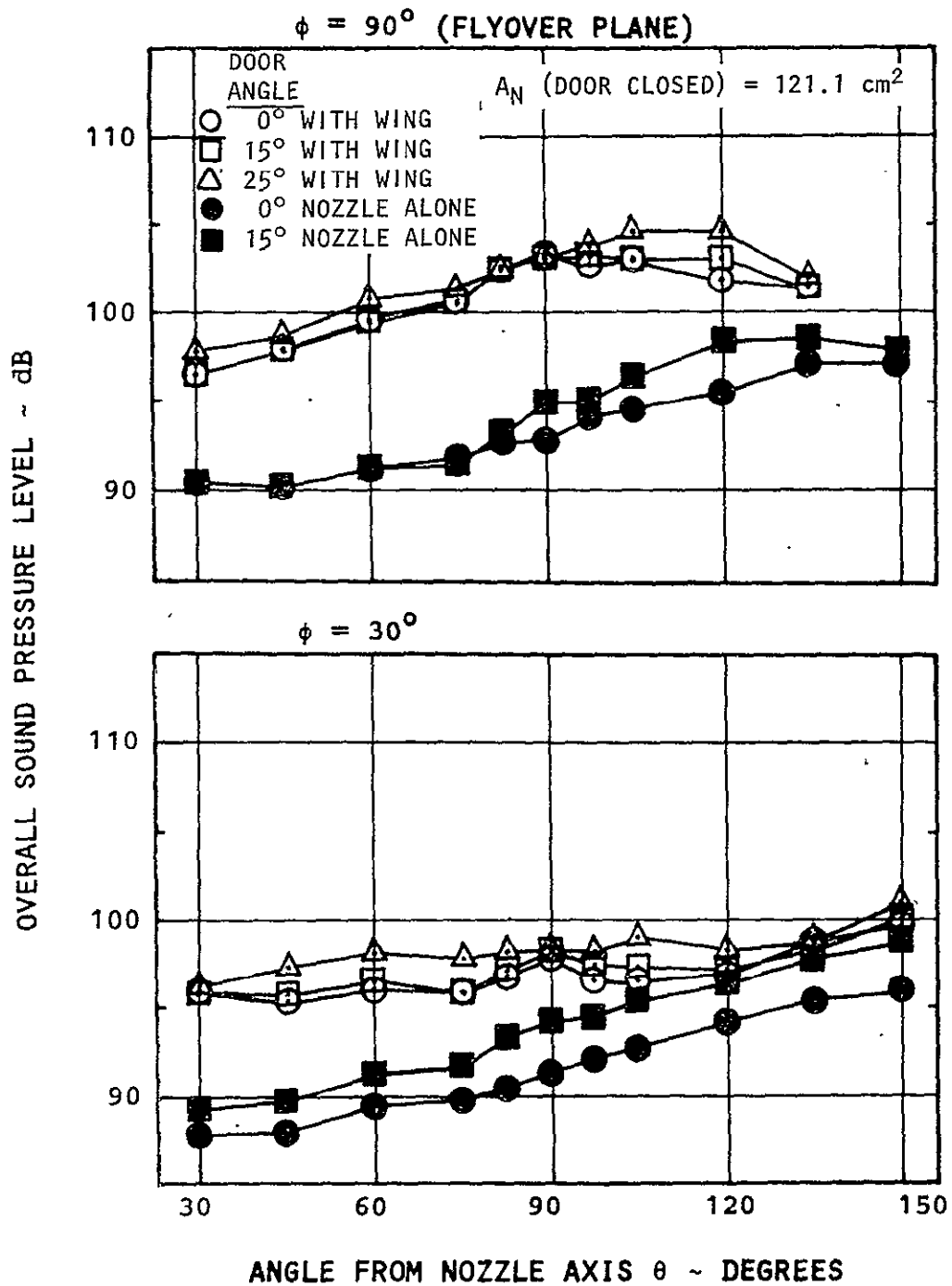


FIGURE 4-12. QCSEE NOZZLE - EFFECT OF DOOR ANGLE ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

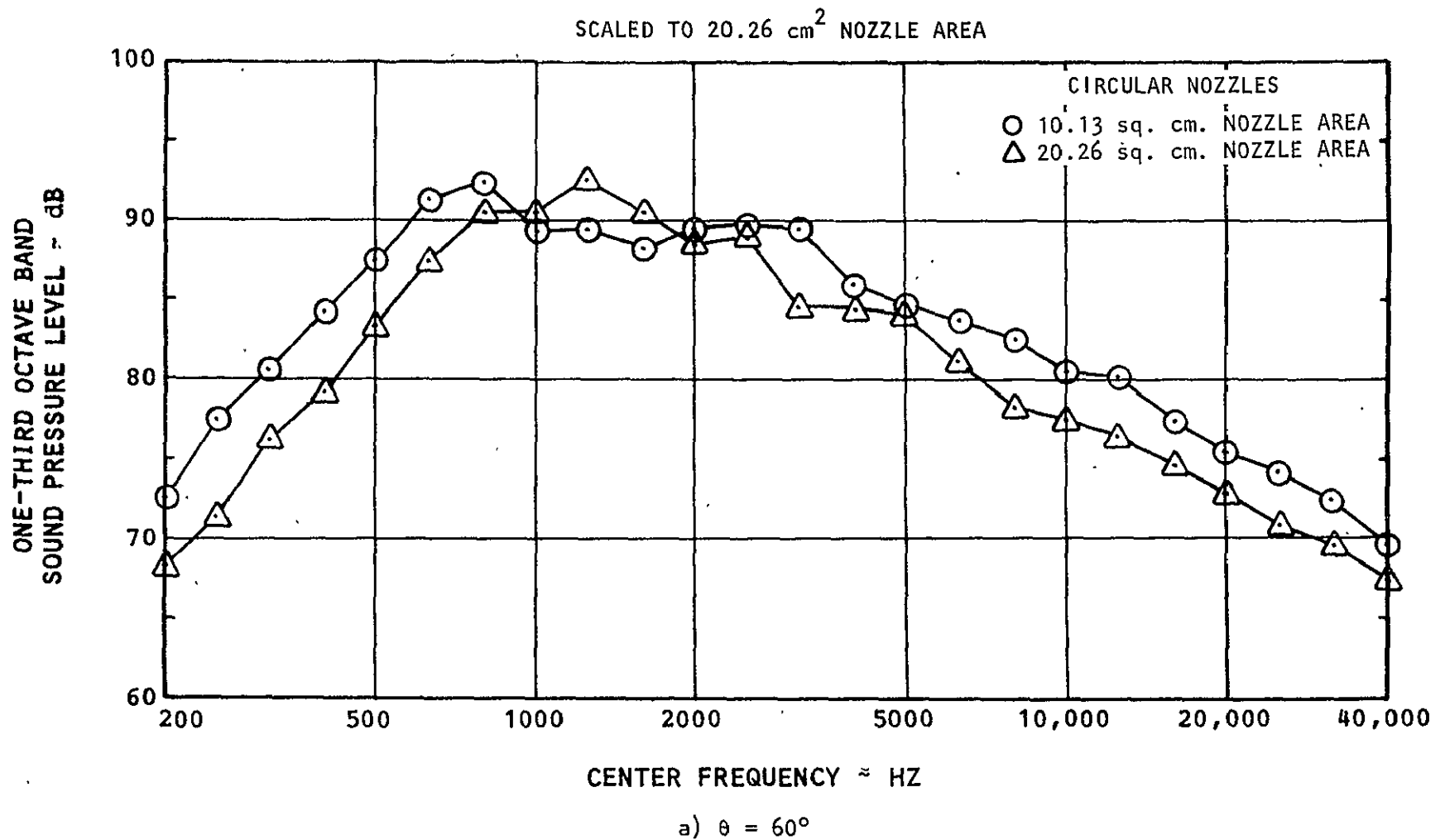


FIGURE 4-13. EFFECT OF NOZZLE AREA ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

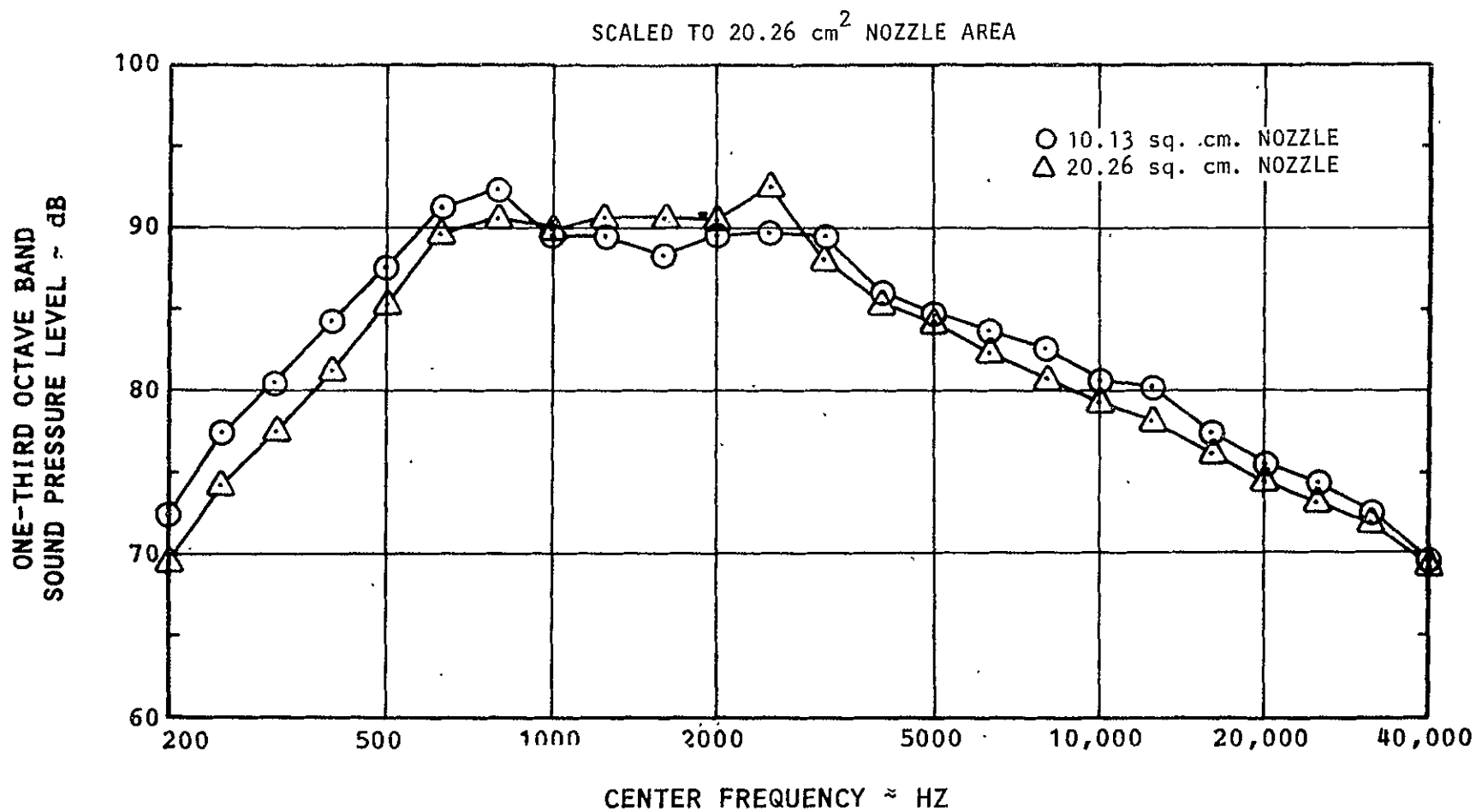
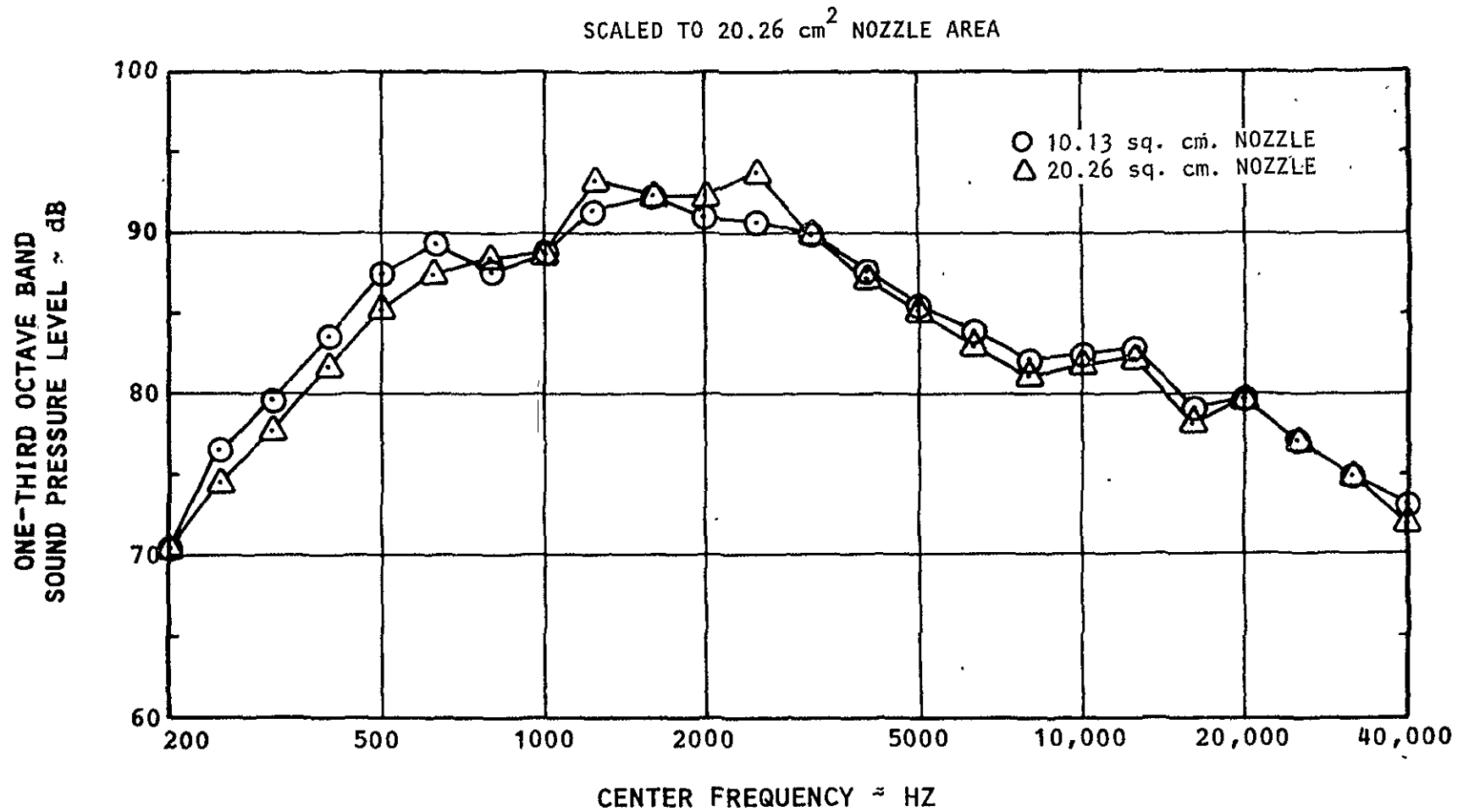
b) $\theta = 90^\circ$

FIGURE 4-13. (CONTINUED)

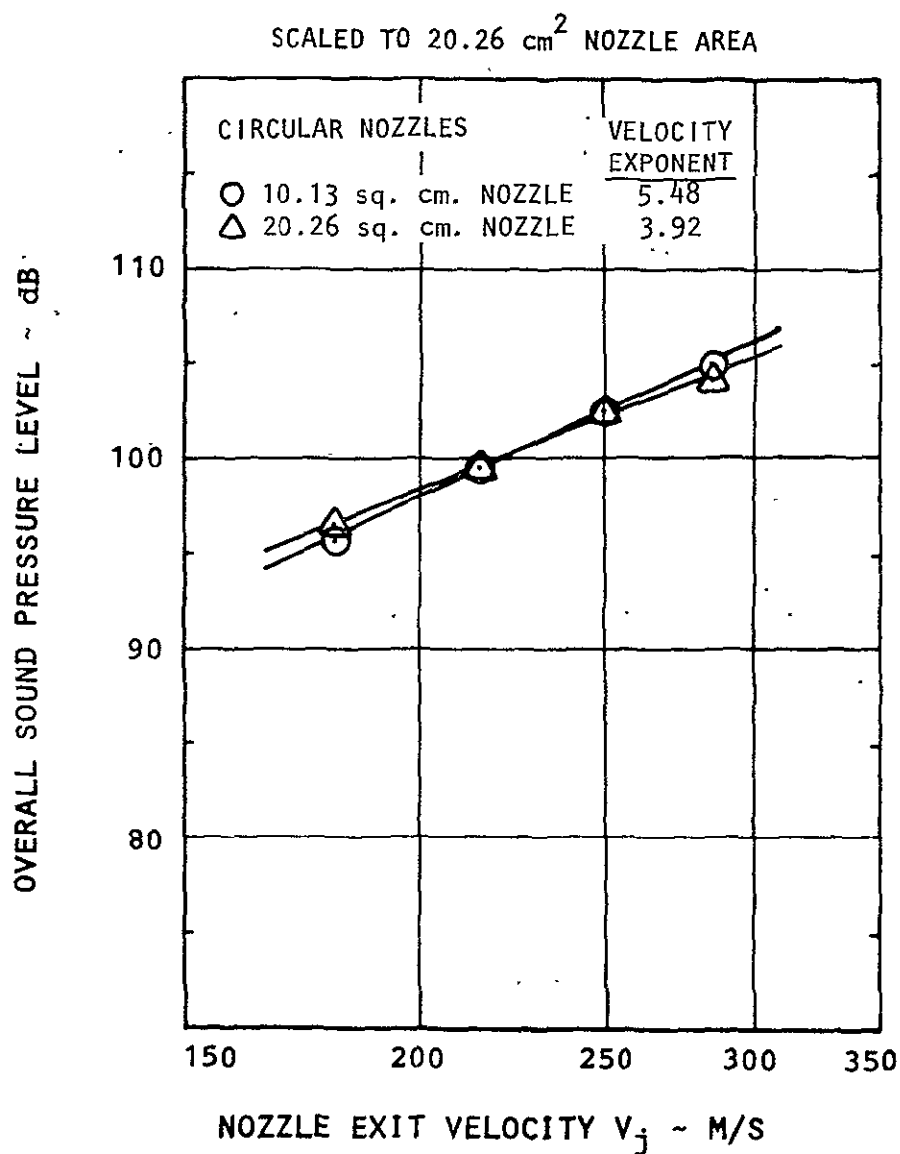
SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-13. (CONCLUDED)

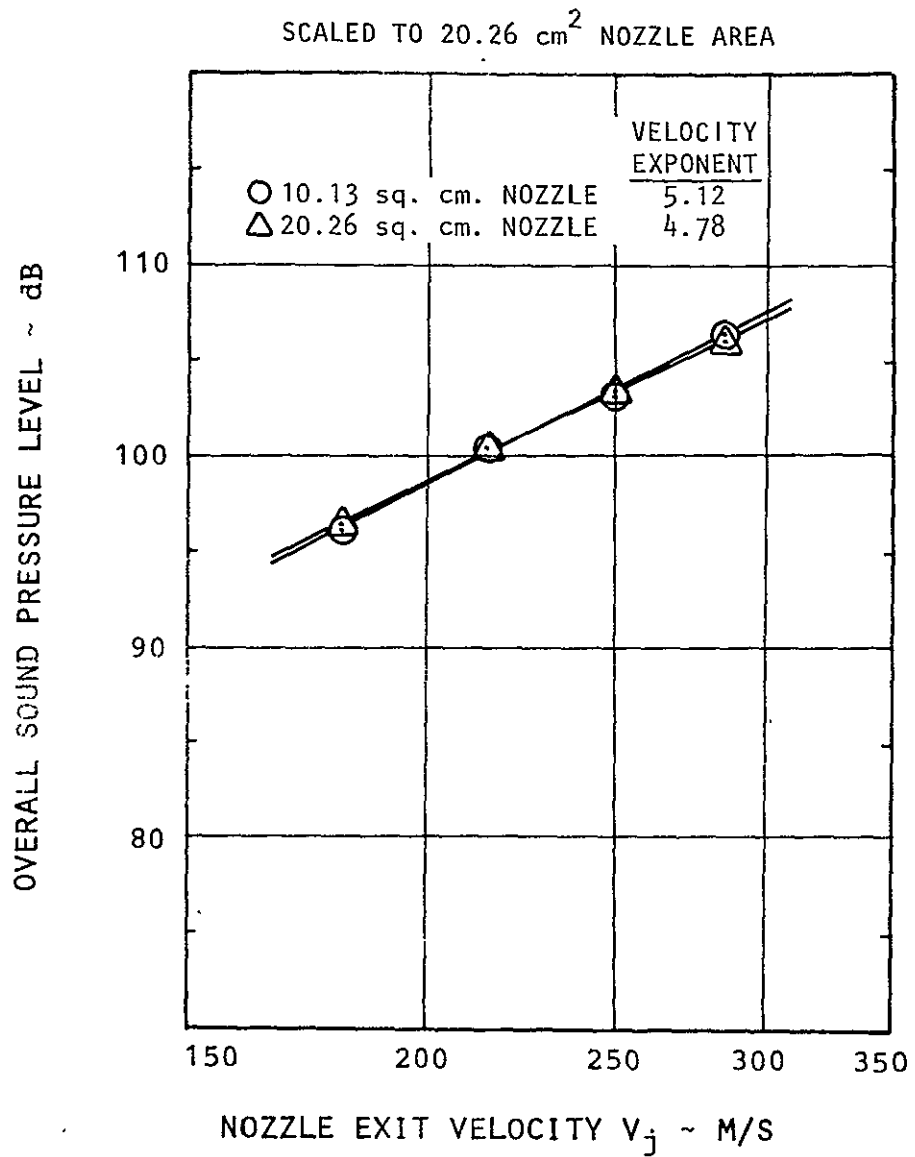
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-14. EFFECT OF NOZZLE AREA ON VELOCITY EXPONENT

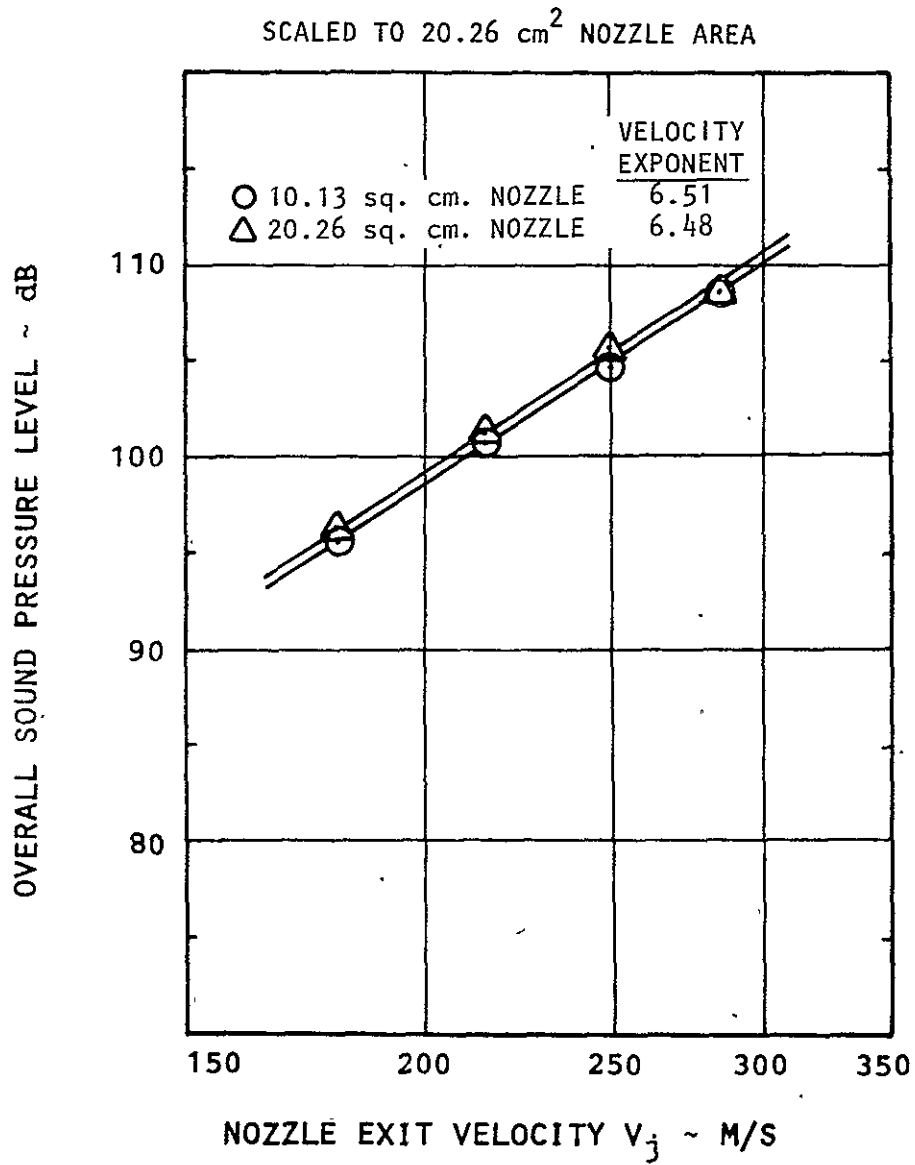
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-14. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



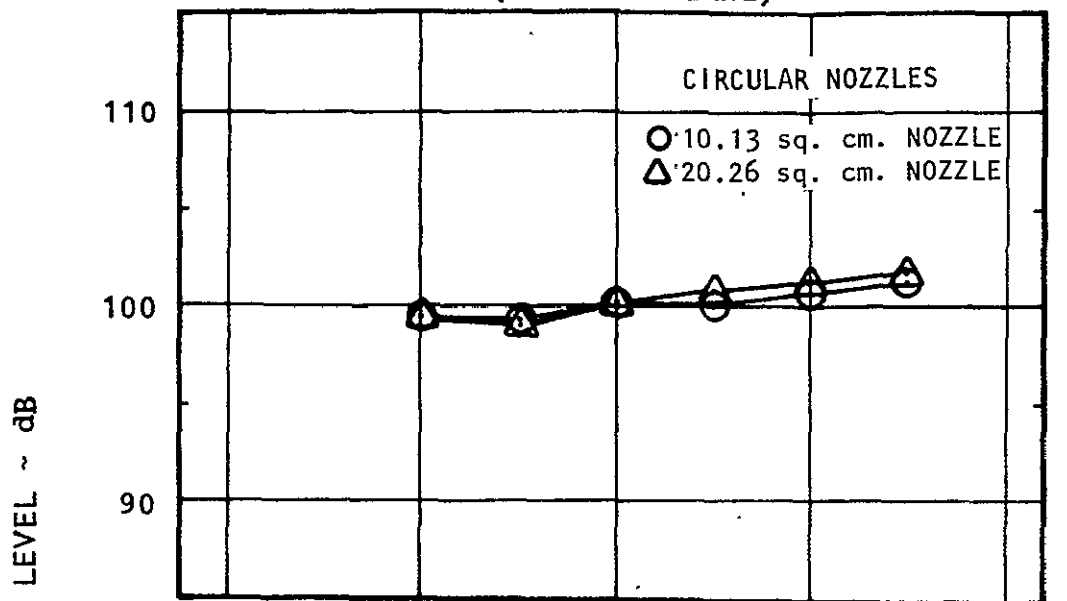
c) $\theta = 120^\circ$

FIGURE 4-14. (CONCLUDED)

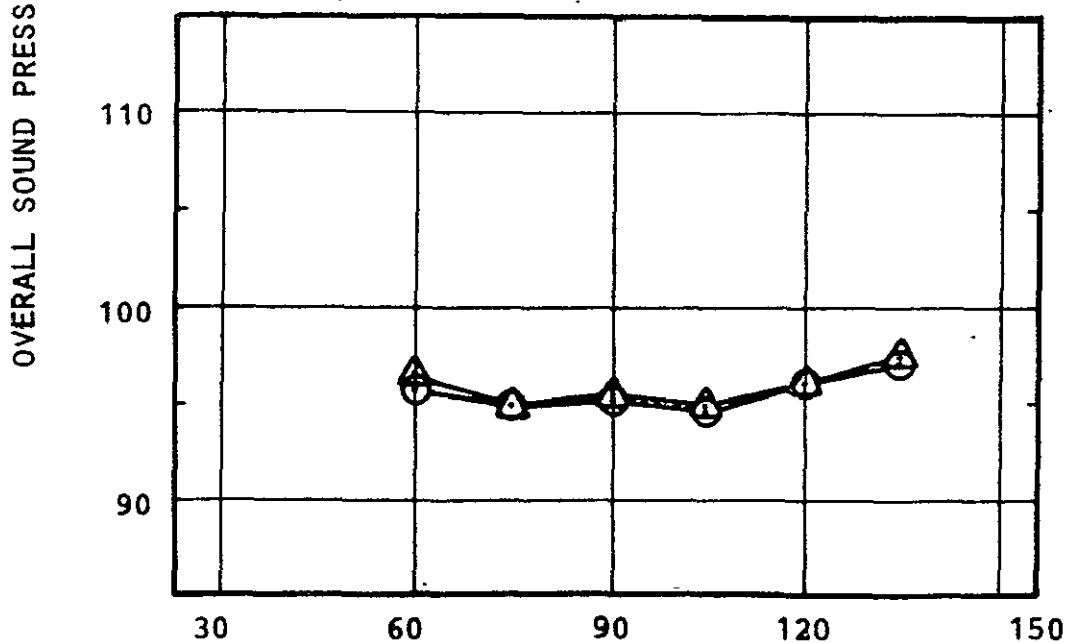
SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

SCALED TO 20.26 cm² NOZZLE AREA

$\phi = 90^\circ$ (FLYOVER PLANE)



$\phi = 30^\circ$

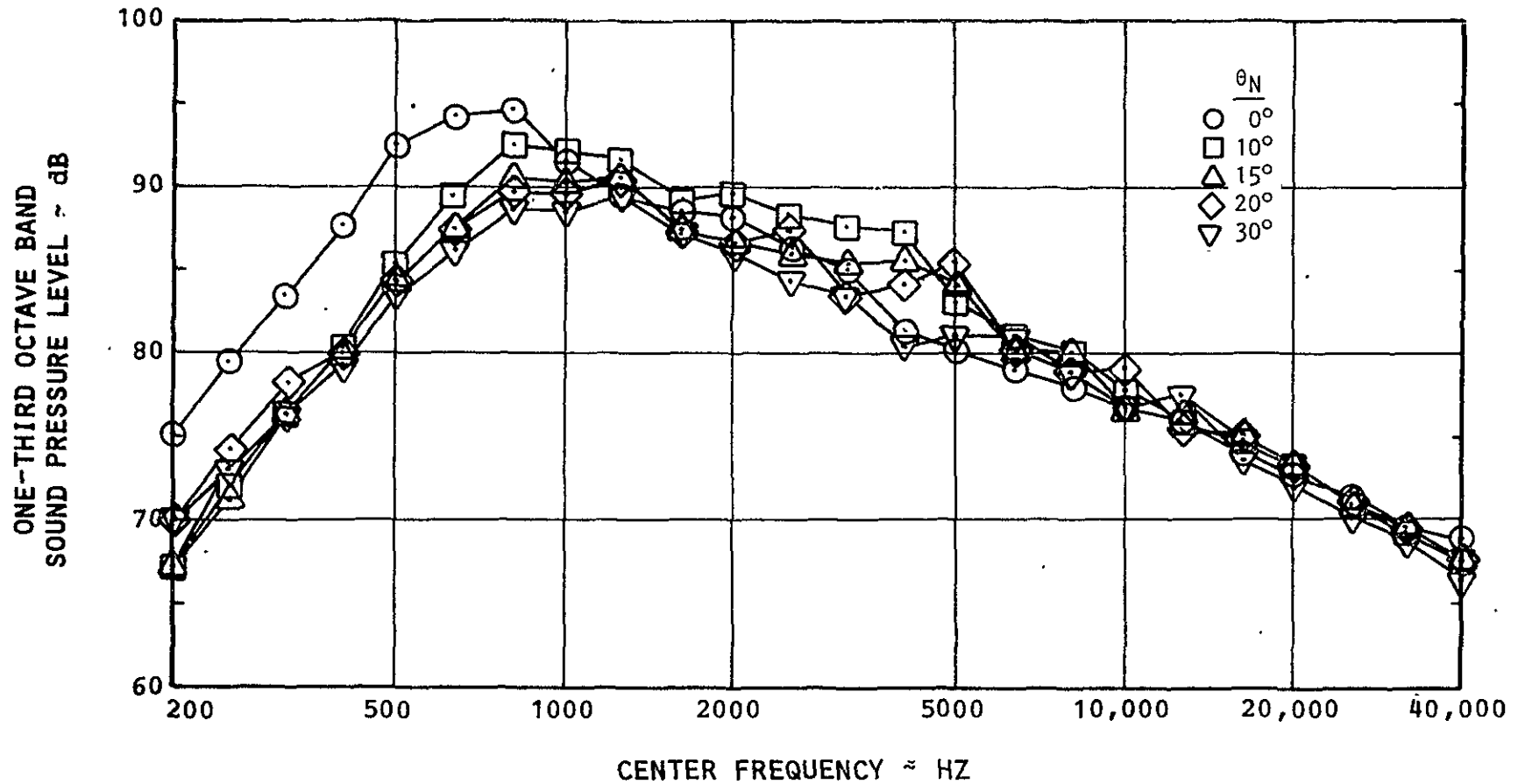


ANGLE FROM NOZZLE AXIS θ ~ DEGREES

FIGURE 4-15. EFFECT OF NOZZLE AREA ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-16. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

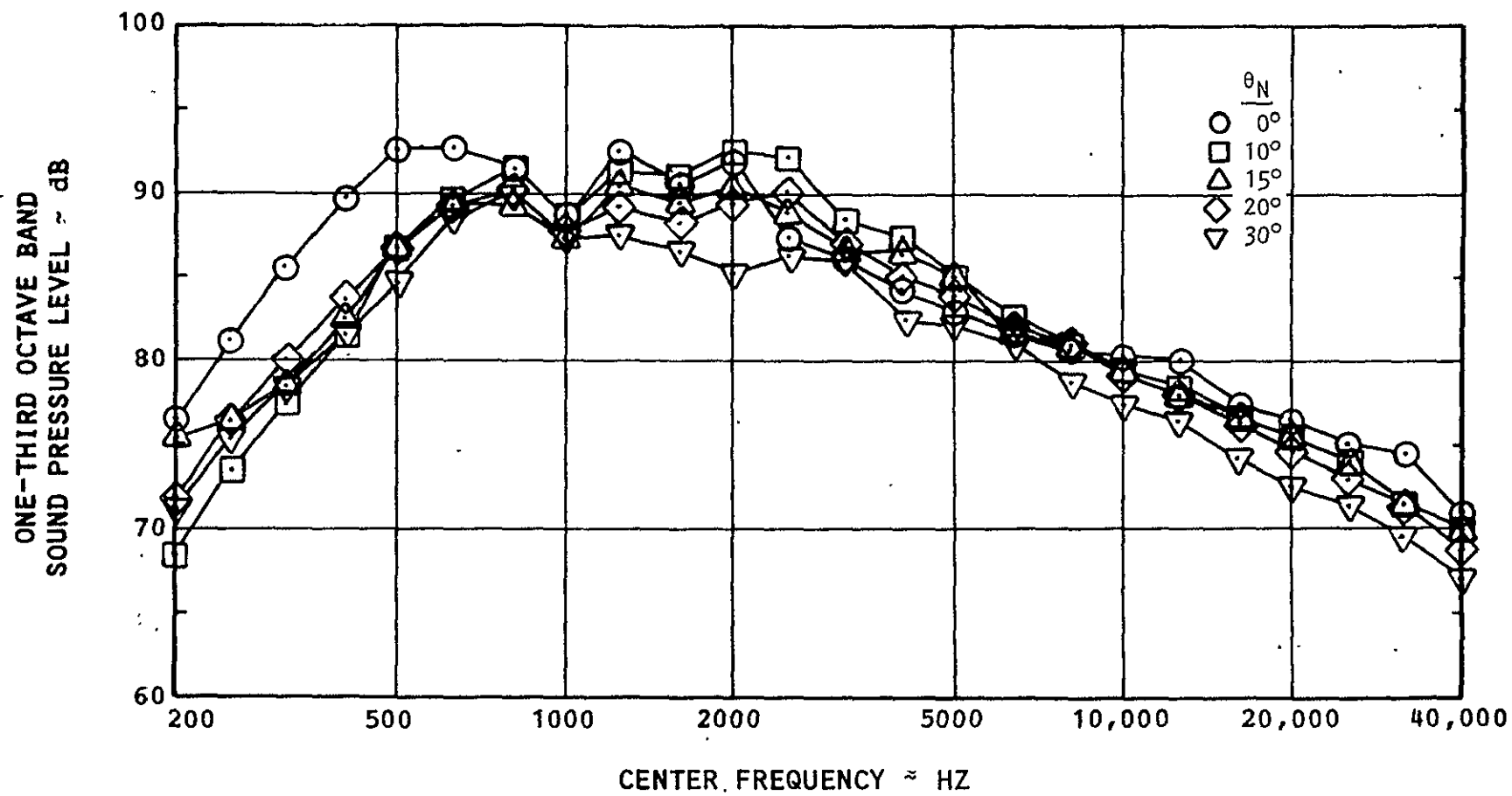
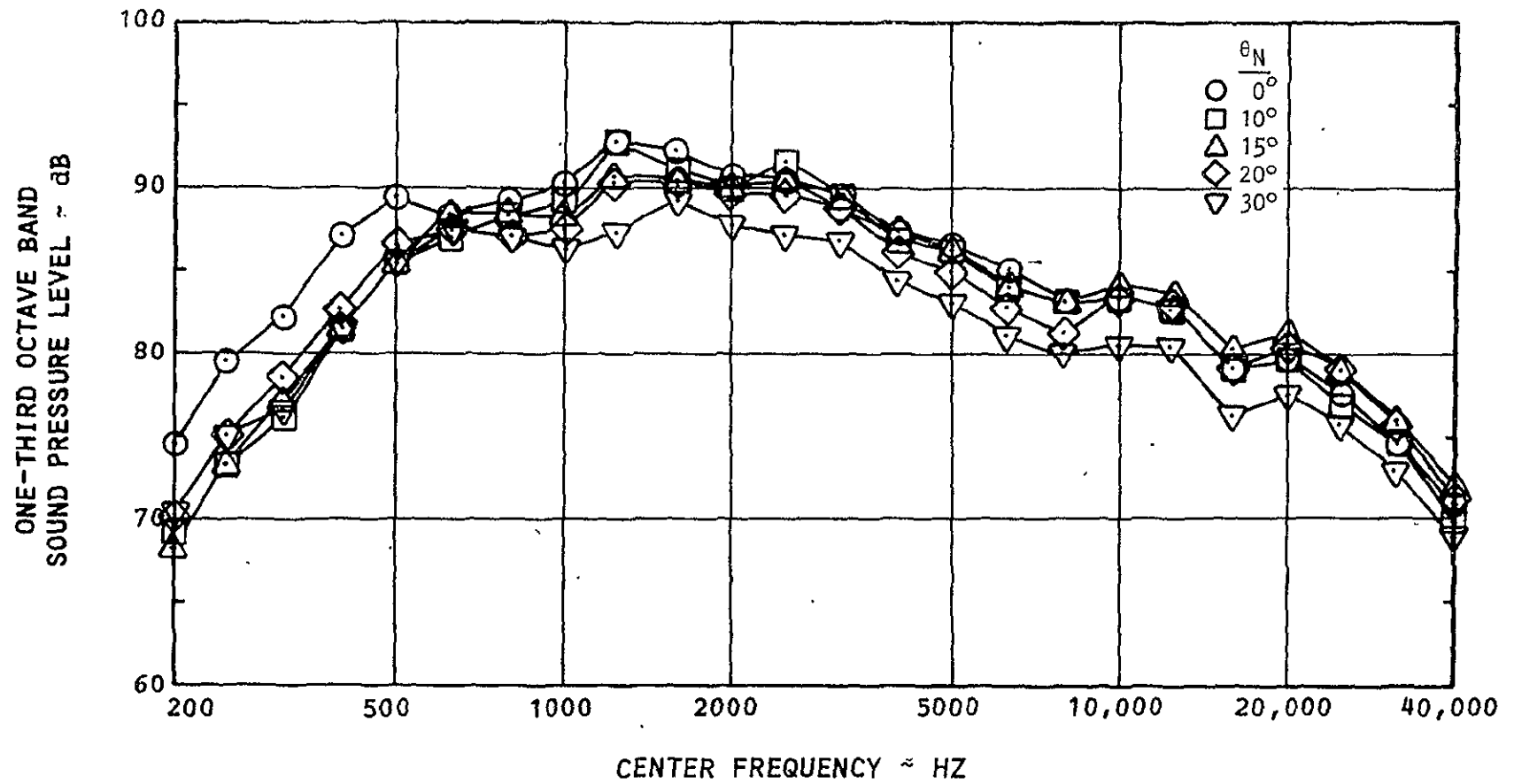
b) $\theta = 90^\circ$

FIGURE 4-16. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-16. (CONCLUDED)

LARGE SCALE MODEL DATA

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

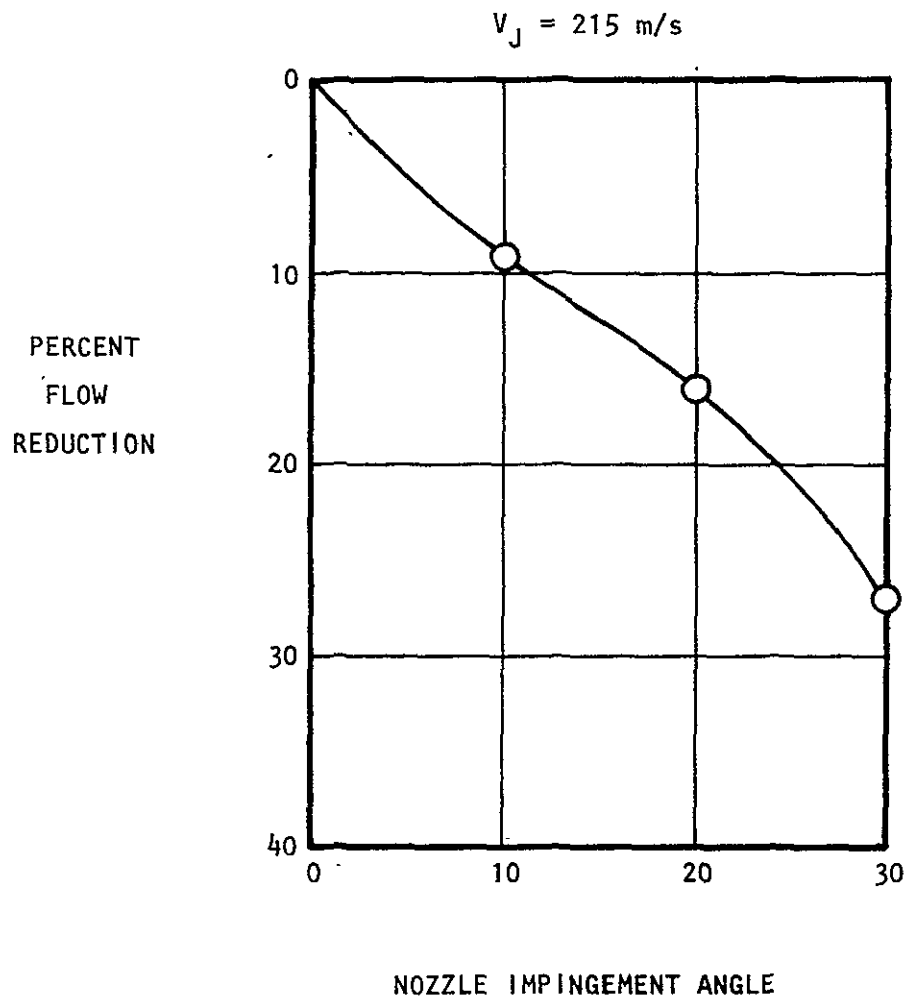


FIGURE 4-17. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON FLOW RATE

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

$$\phi = 90^\circ \quad \theta = 90^\circ$$

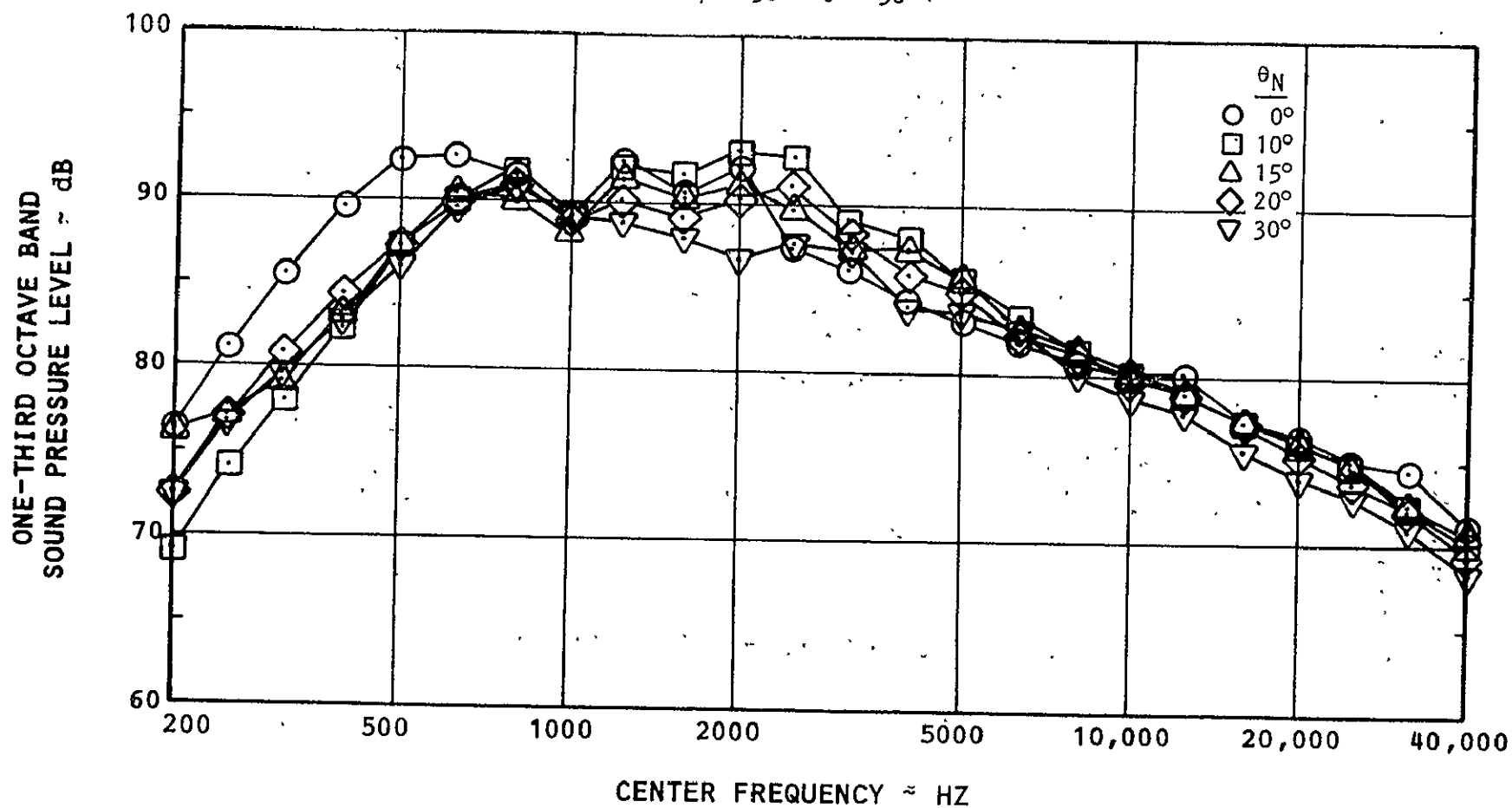


FIGURE 4-18. EFFECT OF NOZZLE IMPINGEMENT ANGLE FOR CONSTANT THRUST

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

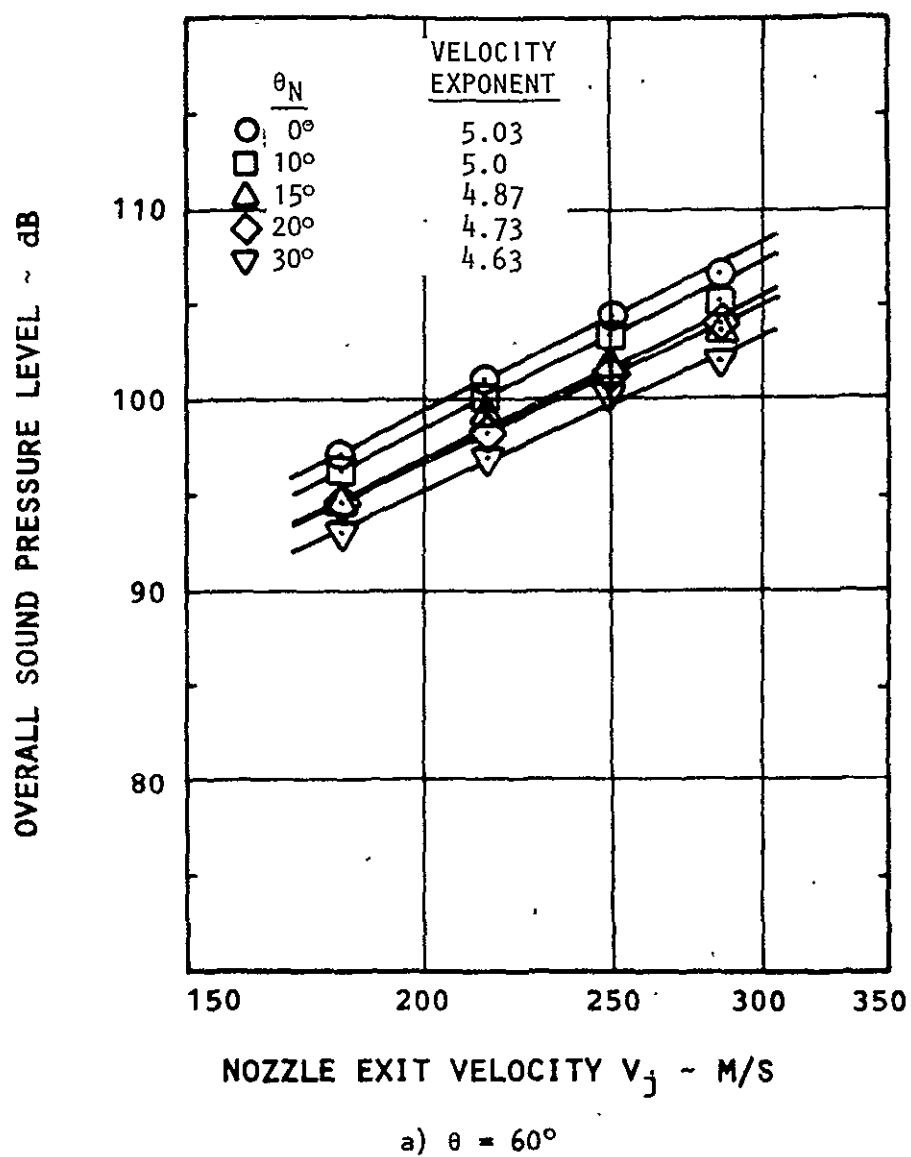
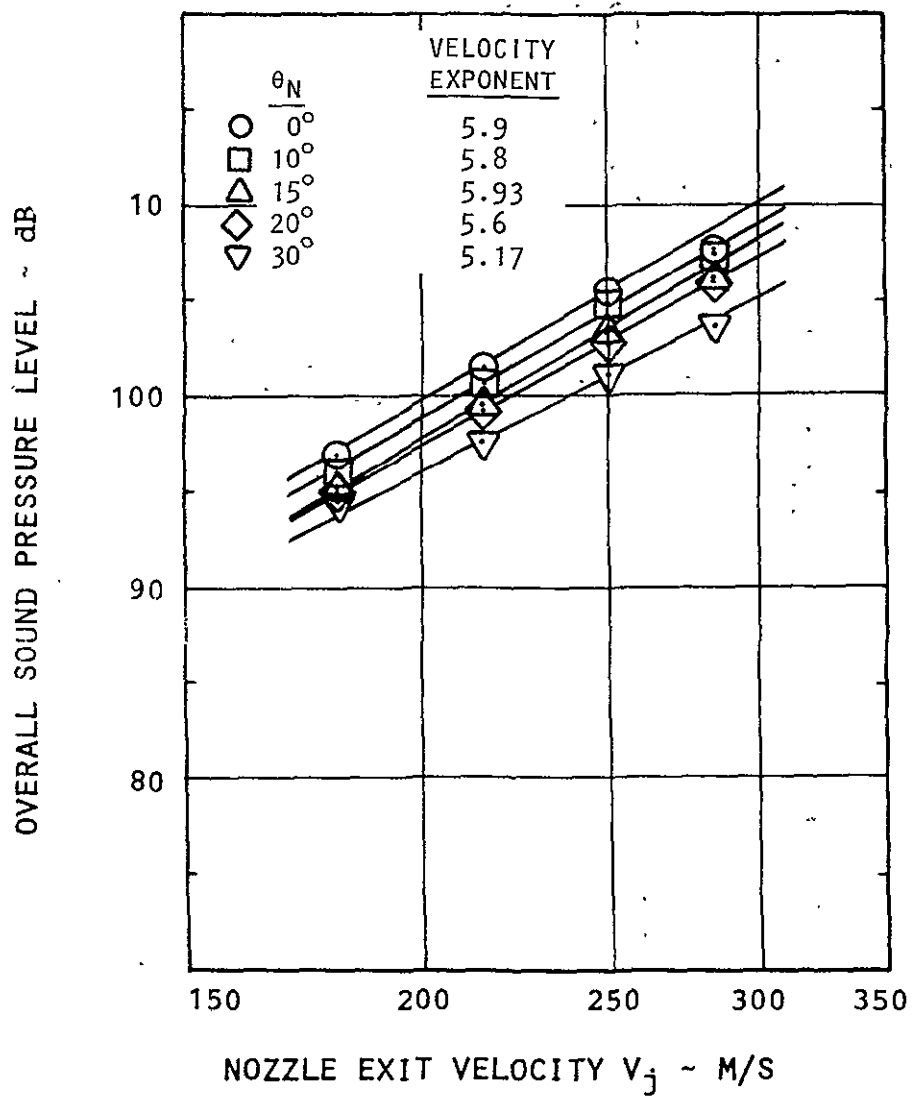


FIGURE 4-19. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON VELOCITY EXPONENT

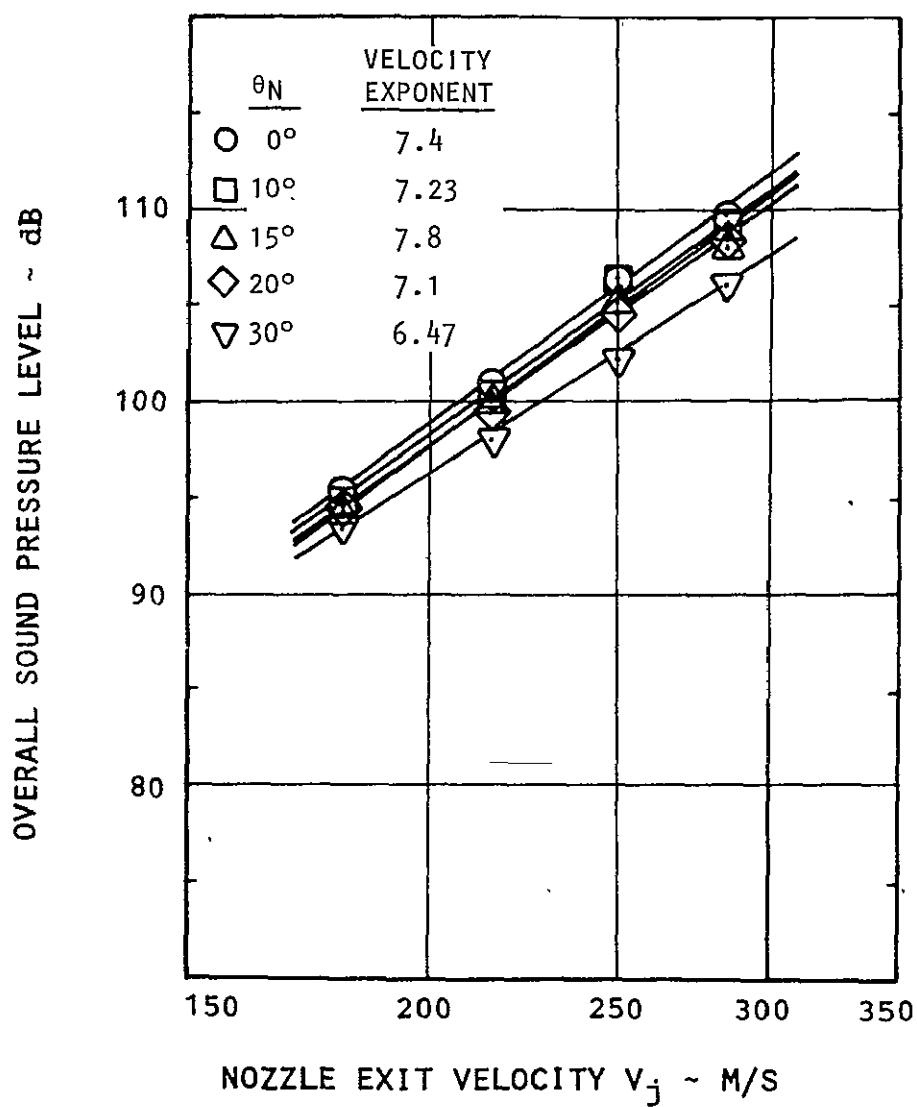
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-19. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-19 (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

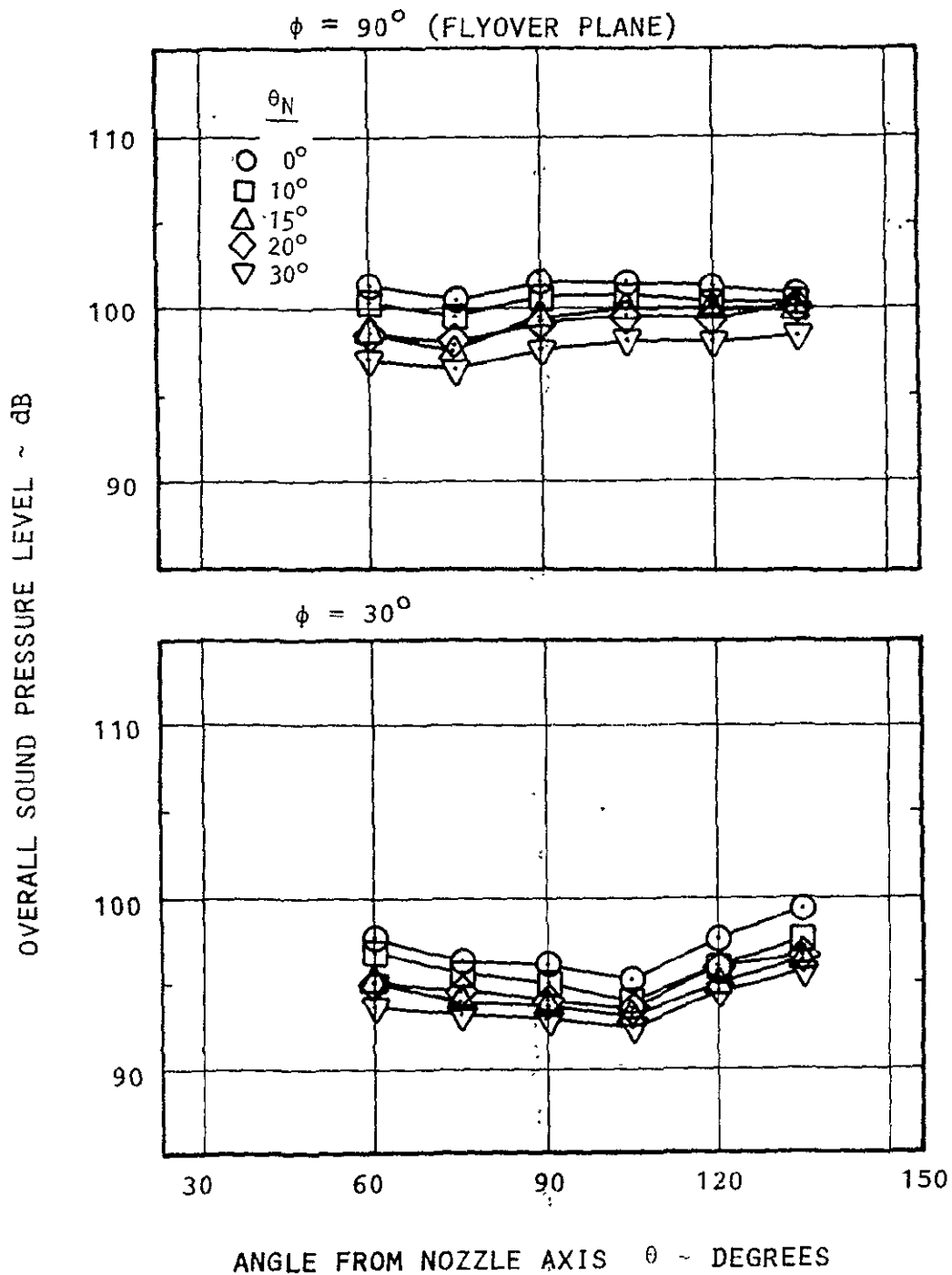
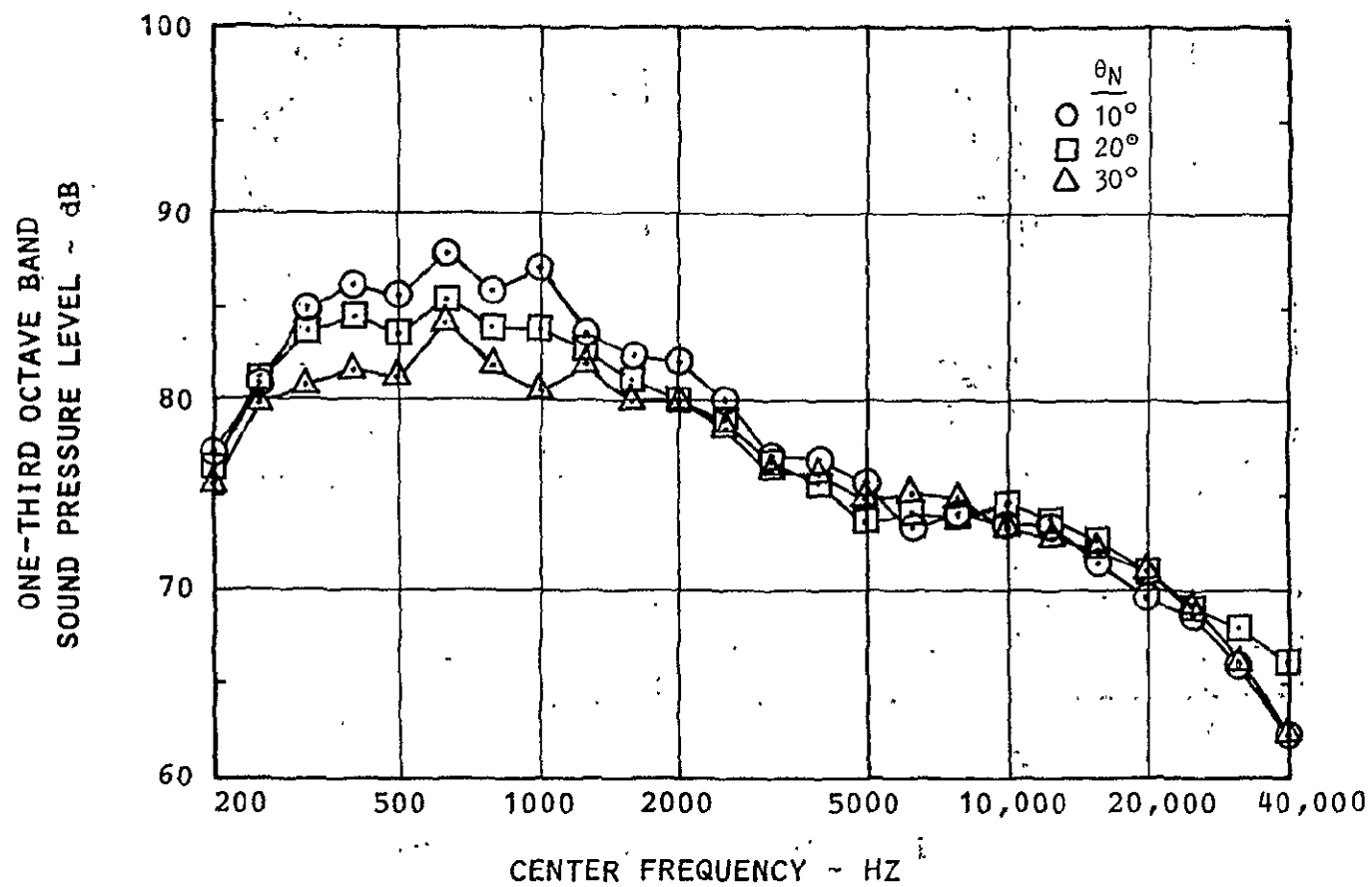


FIGURE 4-20. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON DIRECTIVITY

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-21. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON SPECTRUM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

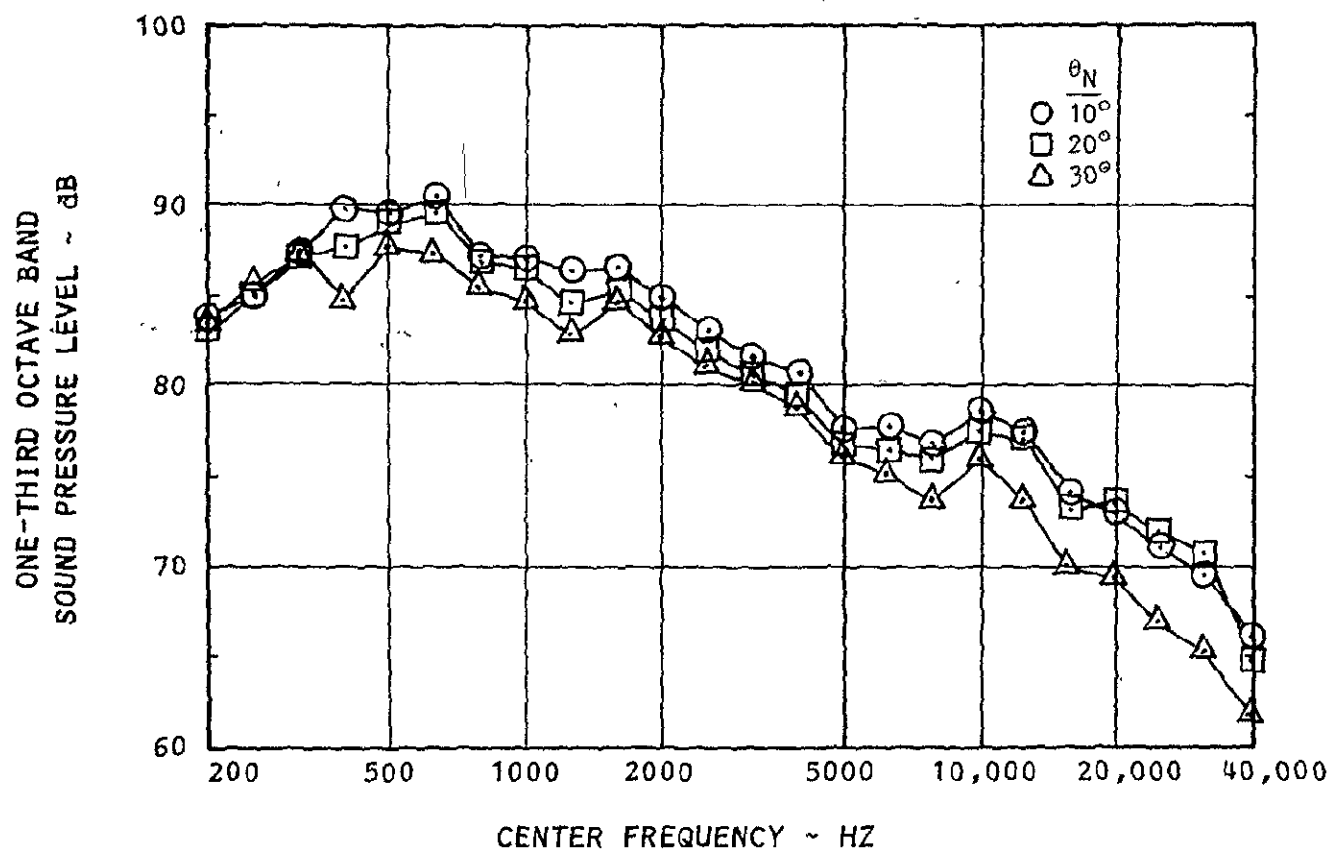
b) $\theta = 120^\circ$

FIGURE 4-21. (CONCLUDED)

LARGE-SCALE MODEL AT 6.1 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

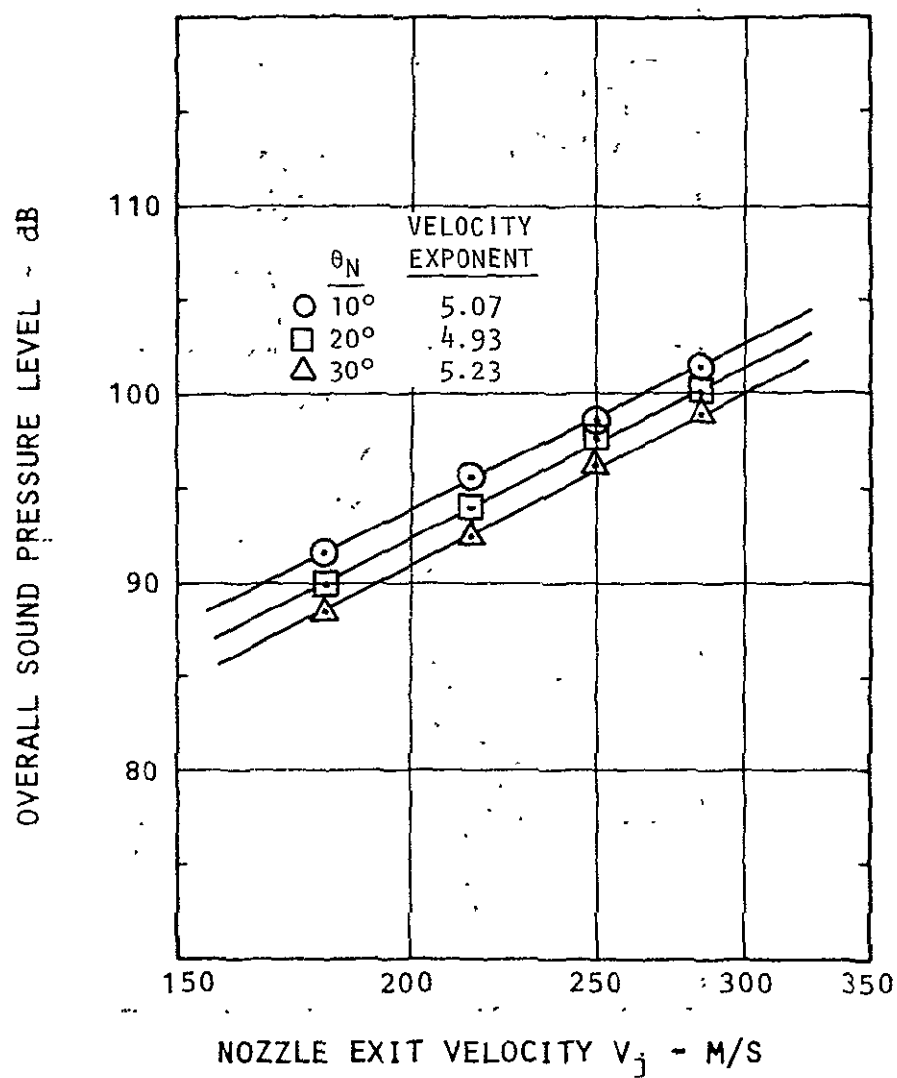


FIGURE 4-22. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON VELOCITY EXPONENT

LARGE-SCALE MODEL AT 6.1 METERS RADIUS

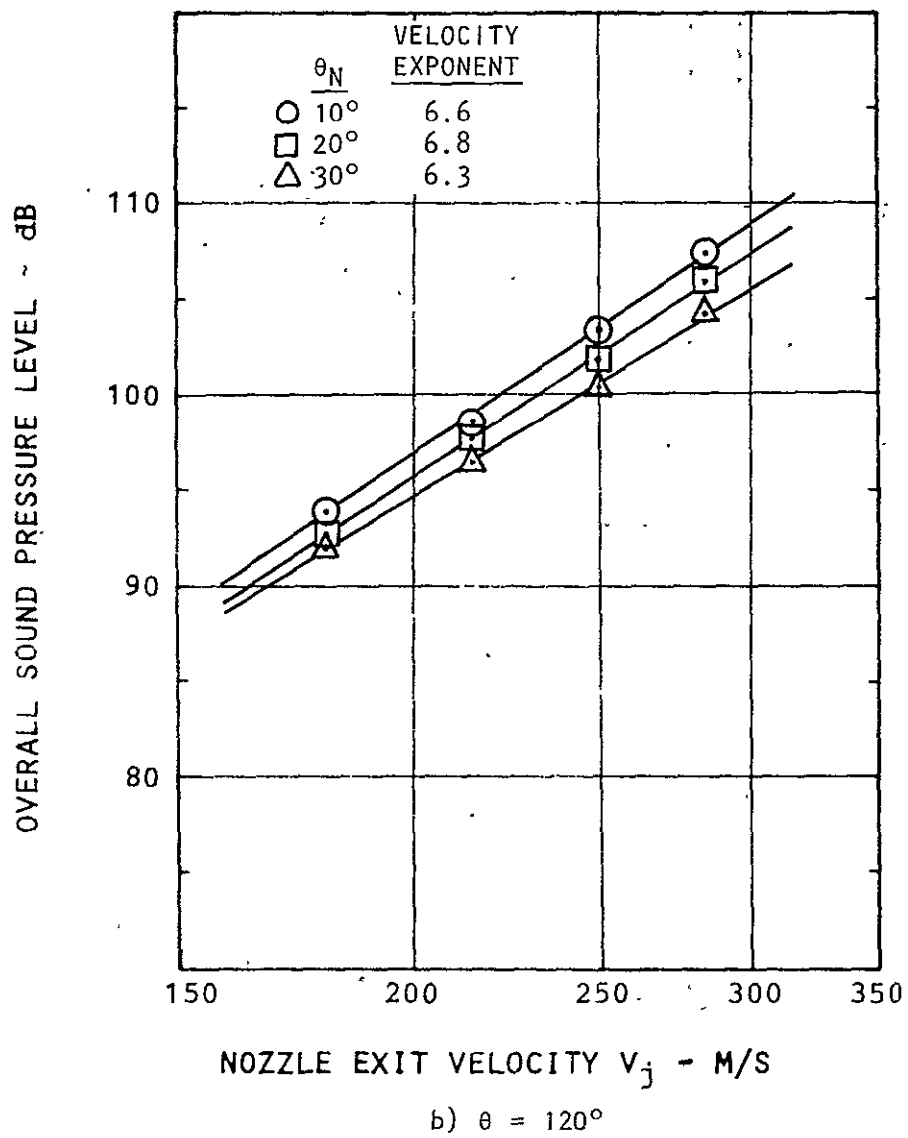


FIGURE 4-22. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

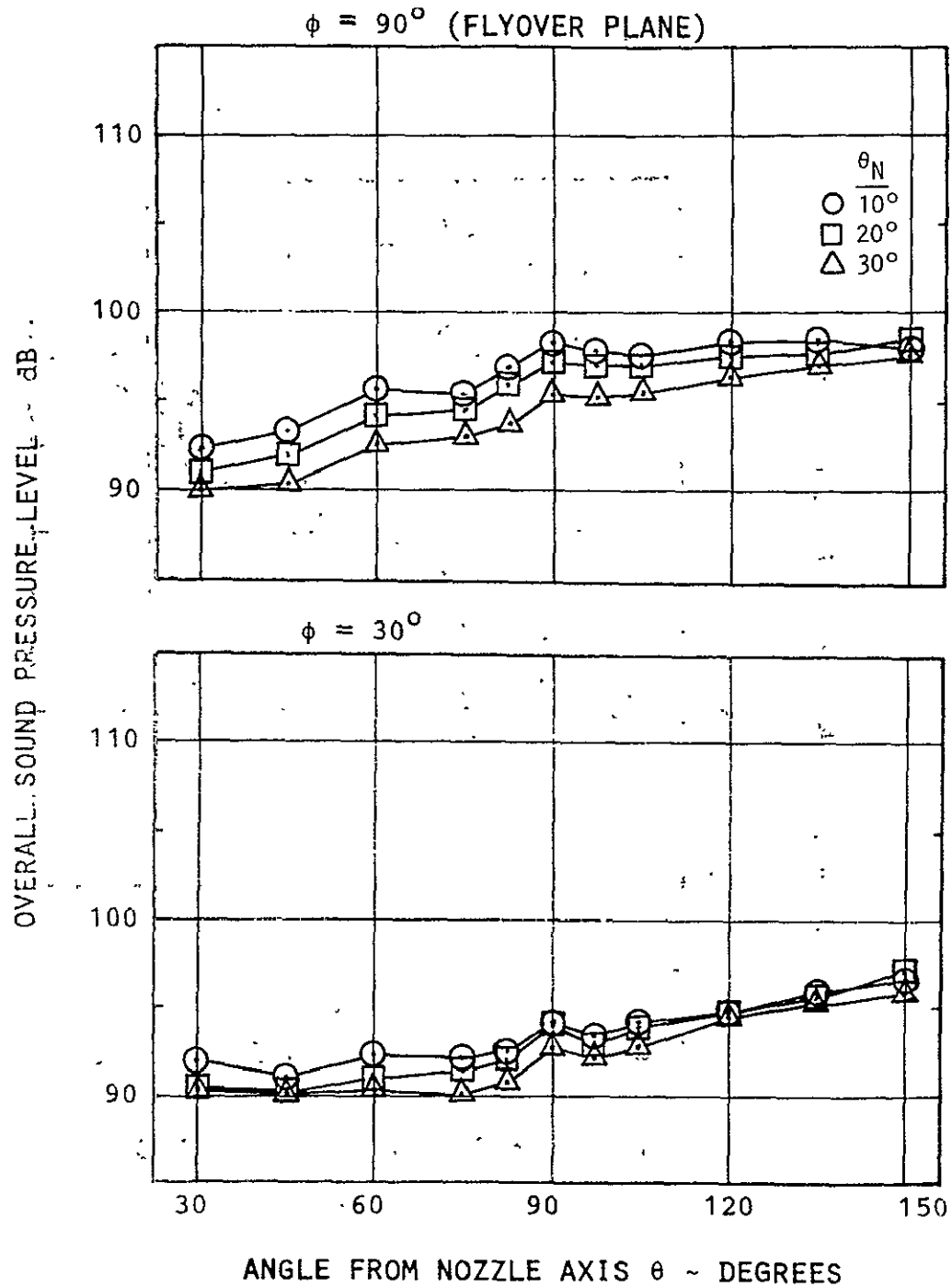


FIGURE 4-23. EFFECT OF NOZZLE IMPINGEMENT ANGLE ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

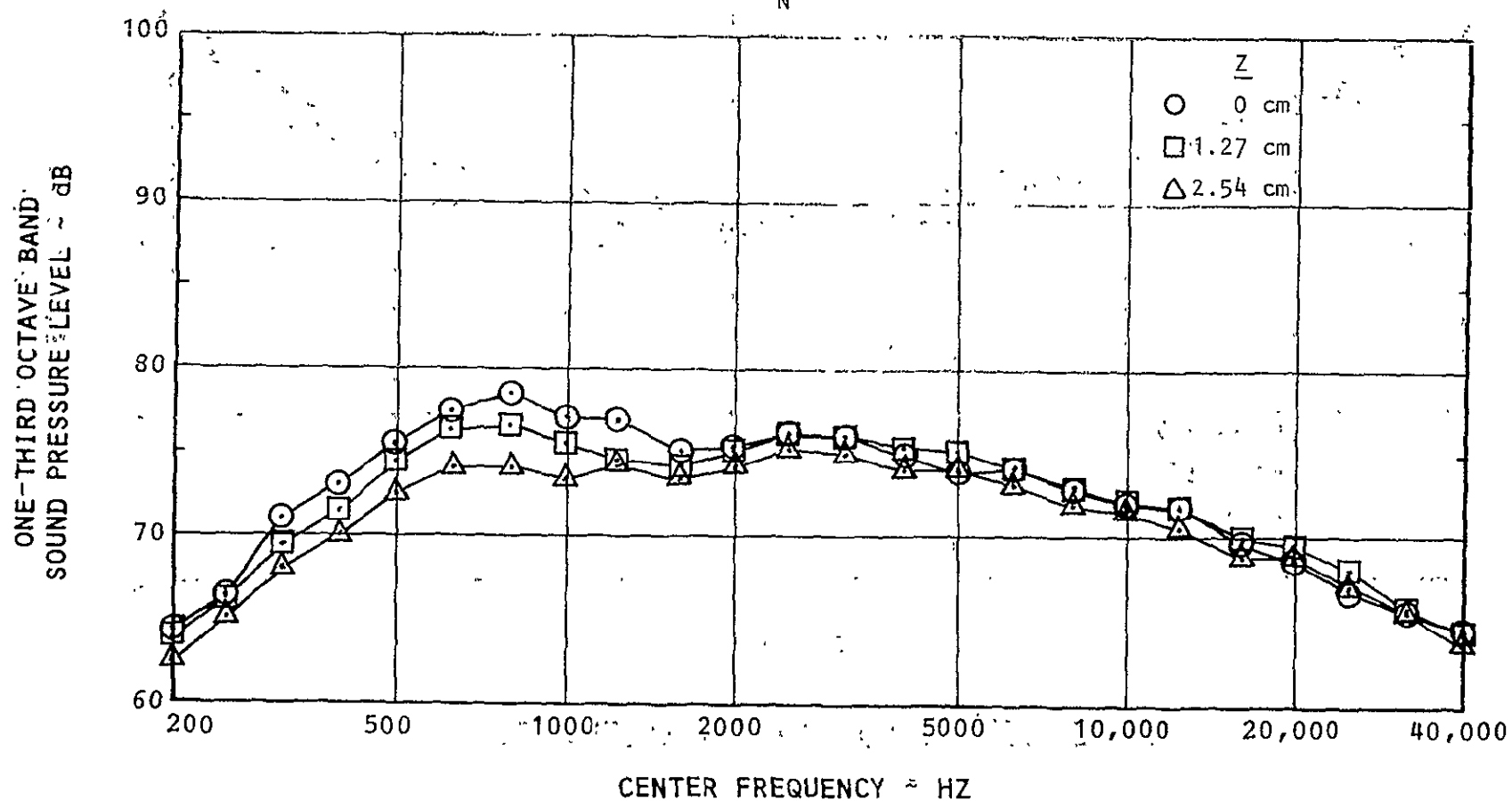
 $\theta_N = 0^\circ$ a) $\theta = 60^\circ$

FIGURE 4-24. EFFECT OF NOZZLE VERTICAL POSITION ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

$$\theta_N = 0^\circ$$

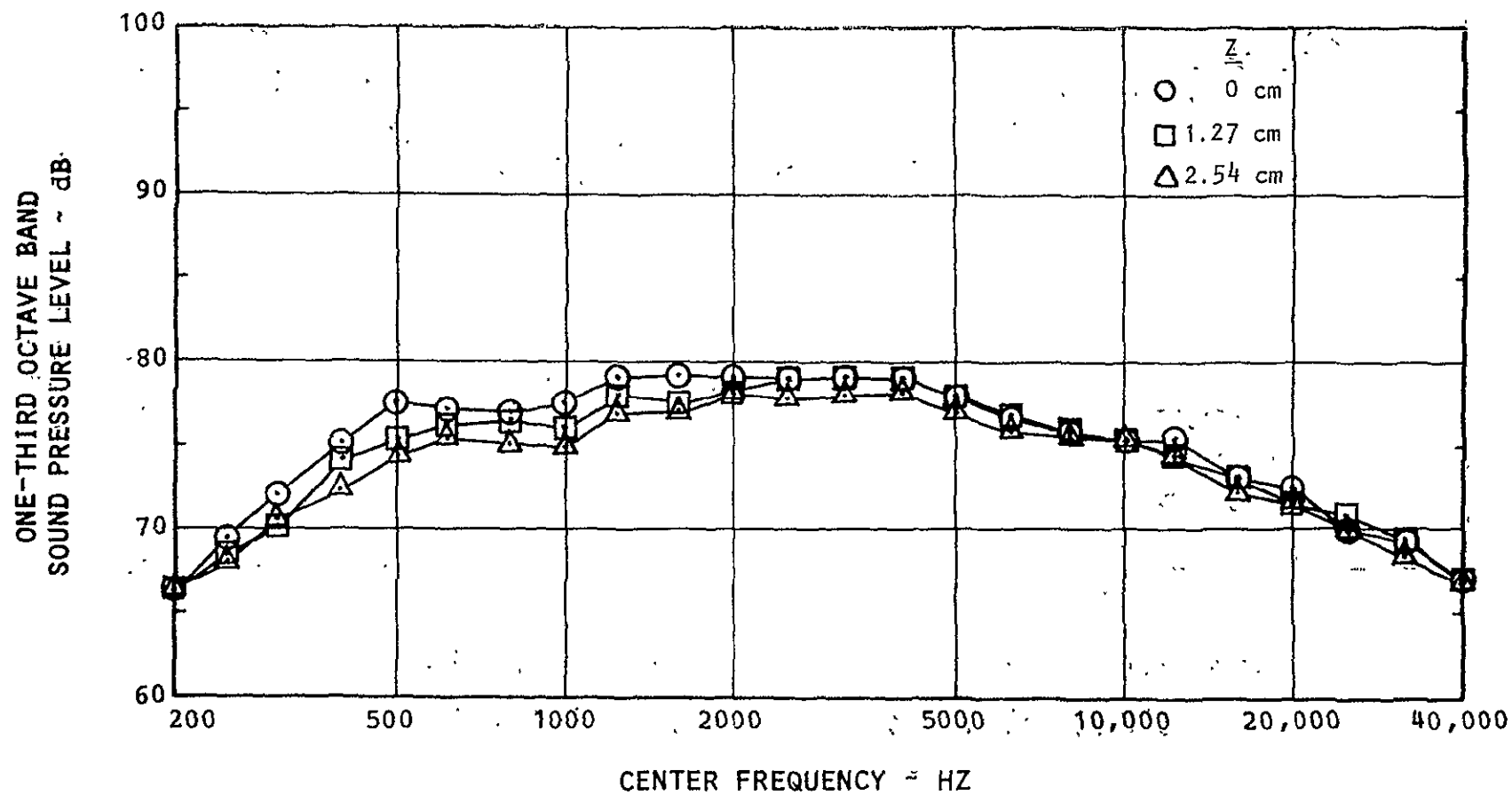
b) $\theta = 90^\circ$

FIGURE 4-24. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

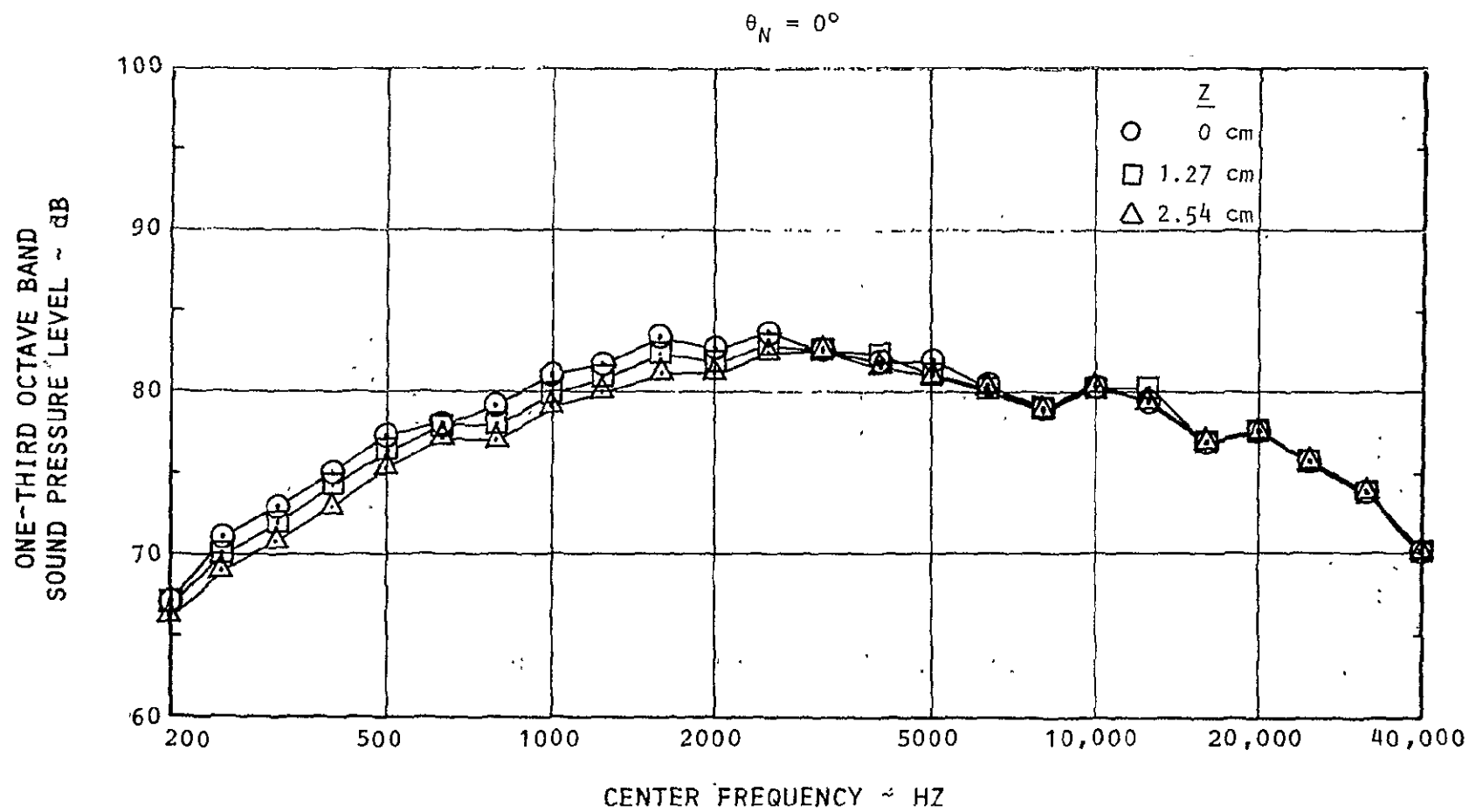
c) $\theta = 120^\circ$

FIGURE 4-24. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

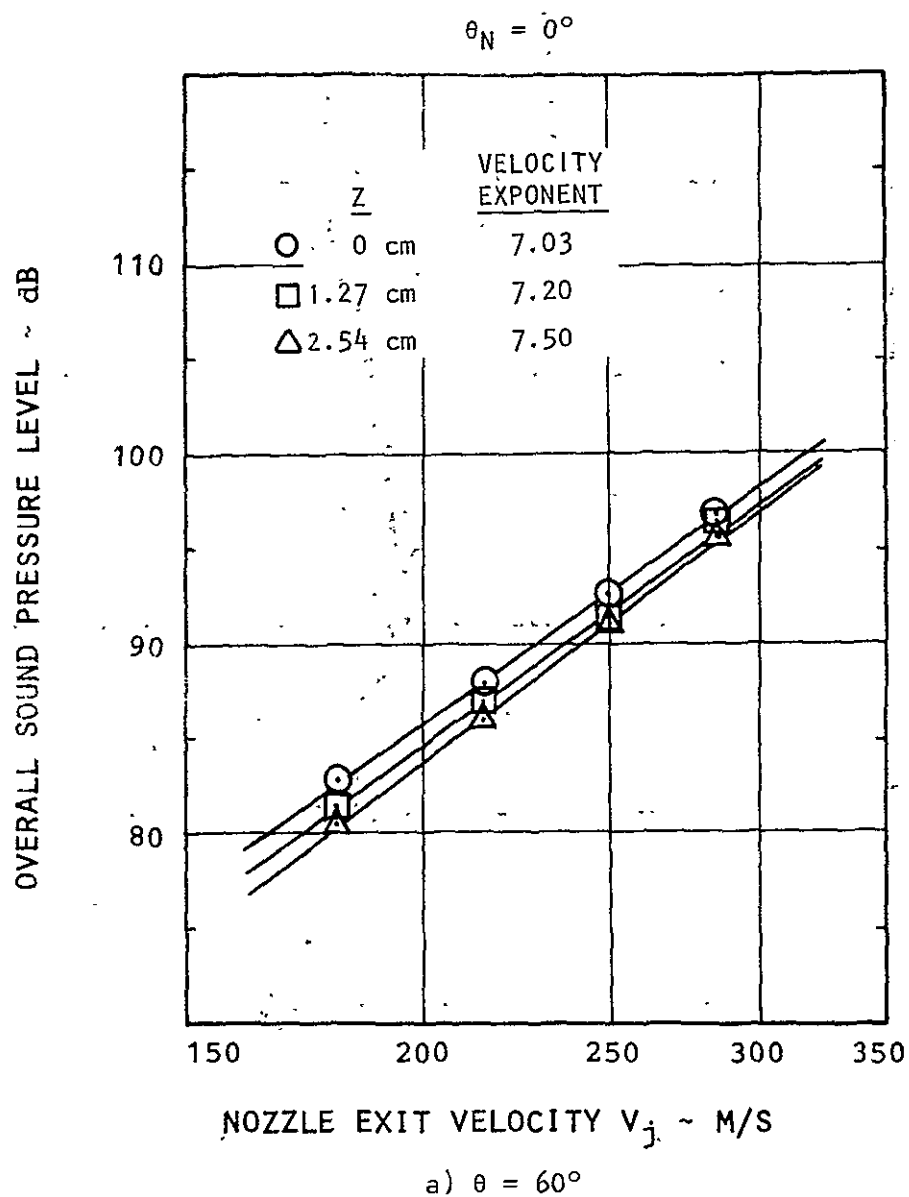


FIGURE 4-25. EFFECT OF NOZZLE VERTICAL POSITION ON VELOCITY EXPONENT

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

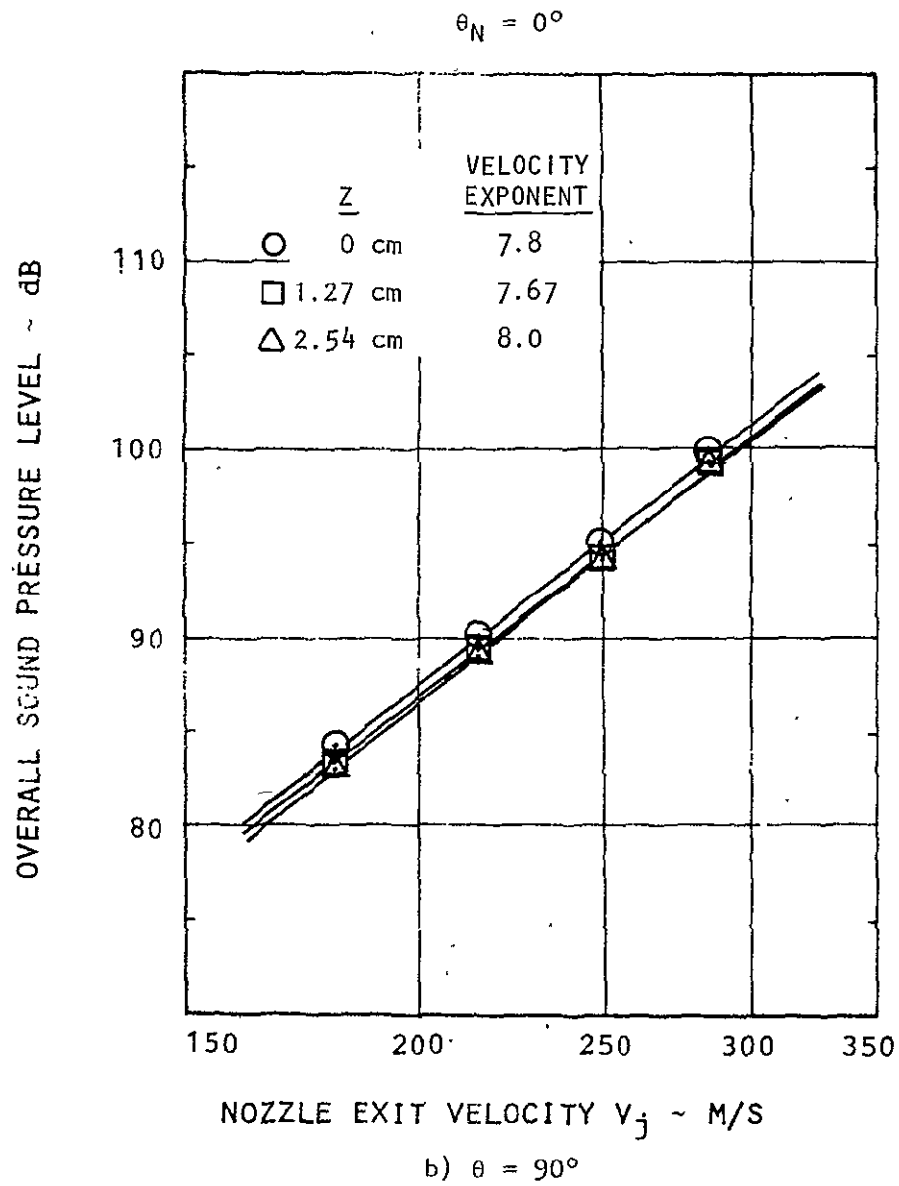


FIGURE 4-25. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

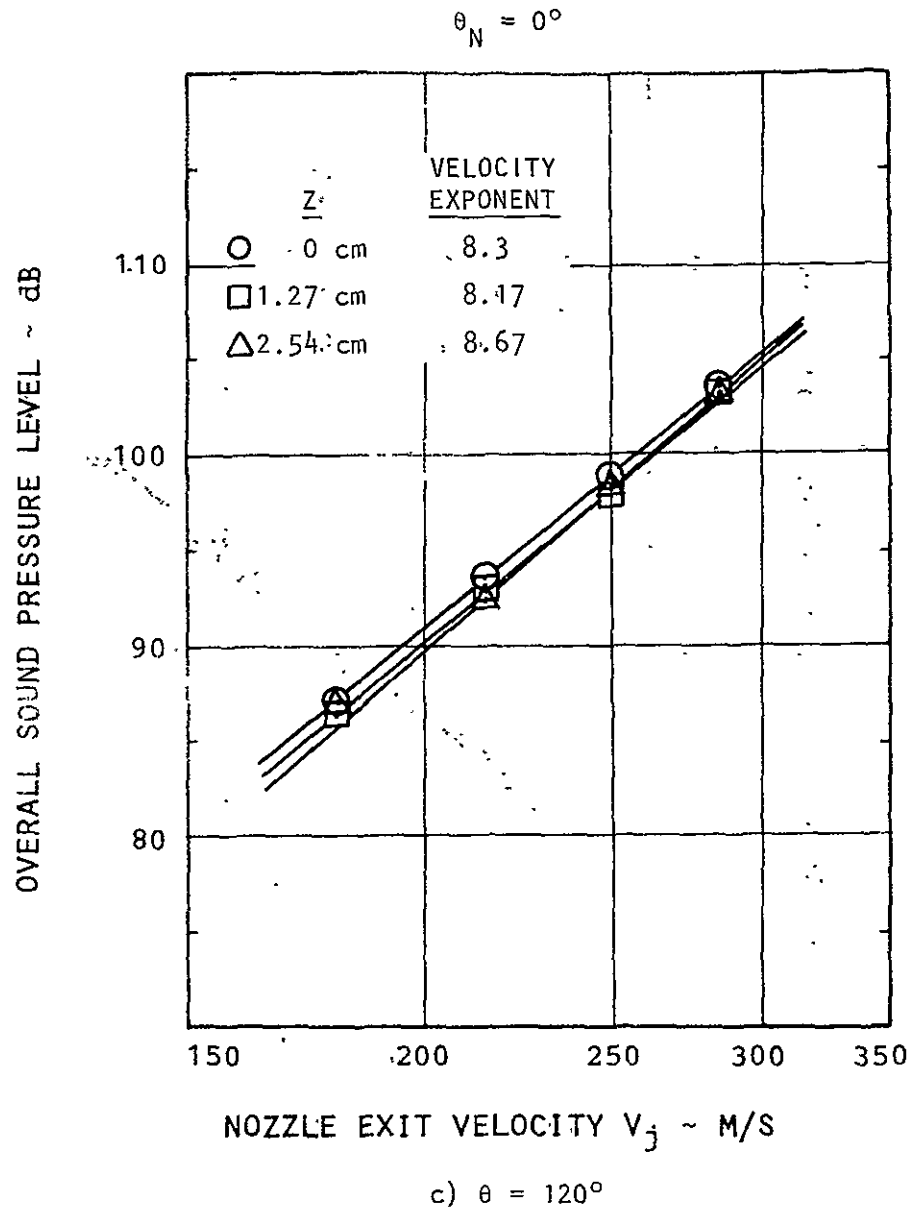


FIGURE 4-25. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

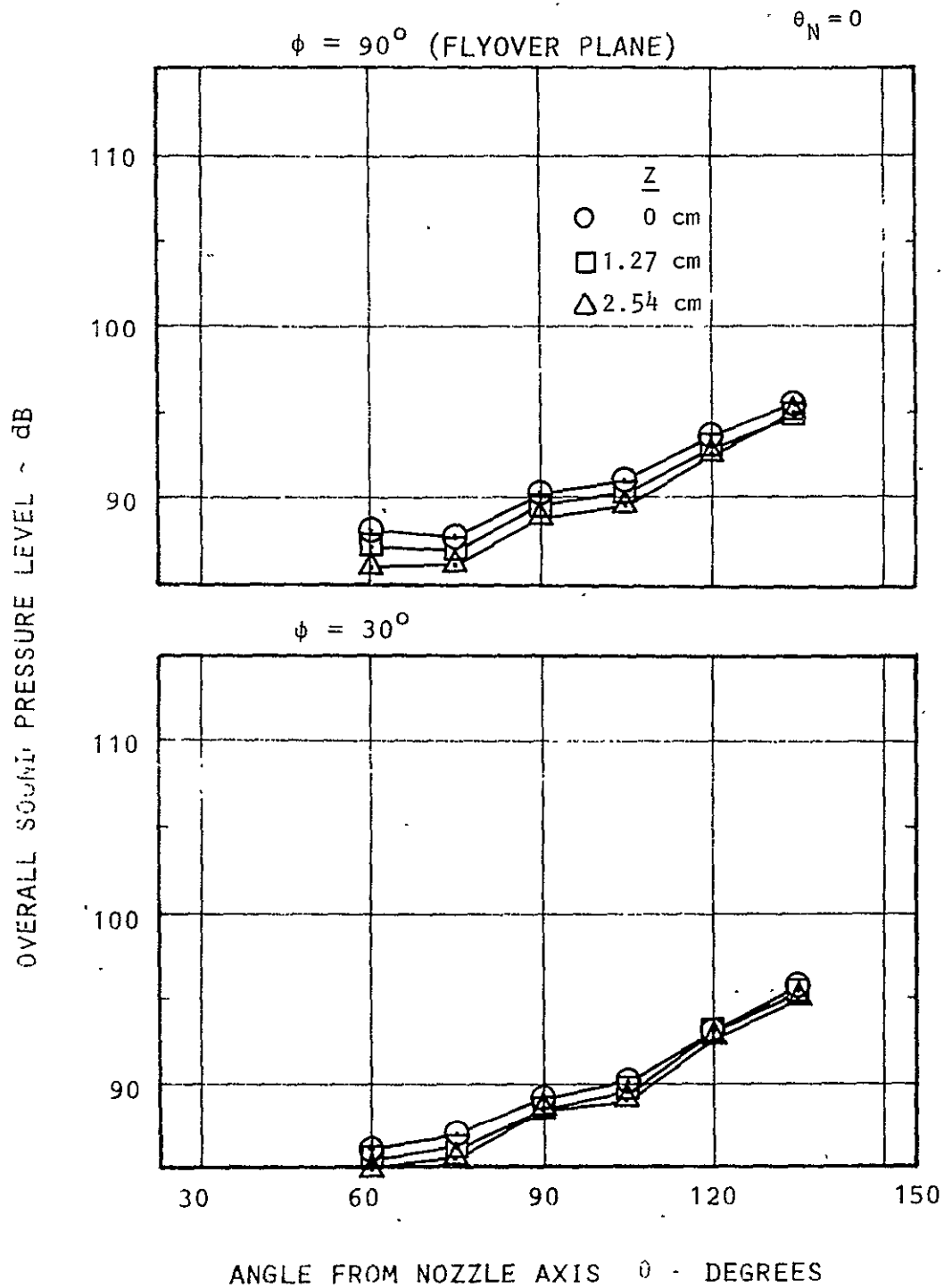


FIGURE 4-26. EFFECT OF NOZZLE VERTICAL POSITION ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

AR8 NOZZLE

$\phi = 90^\circ$ $\theta = 90^\circ$

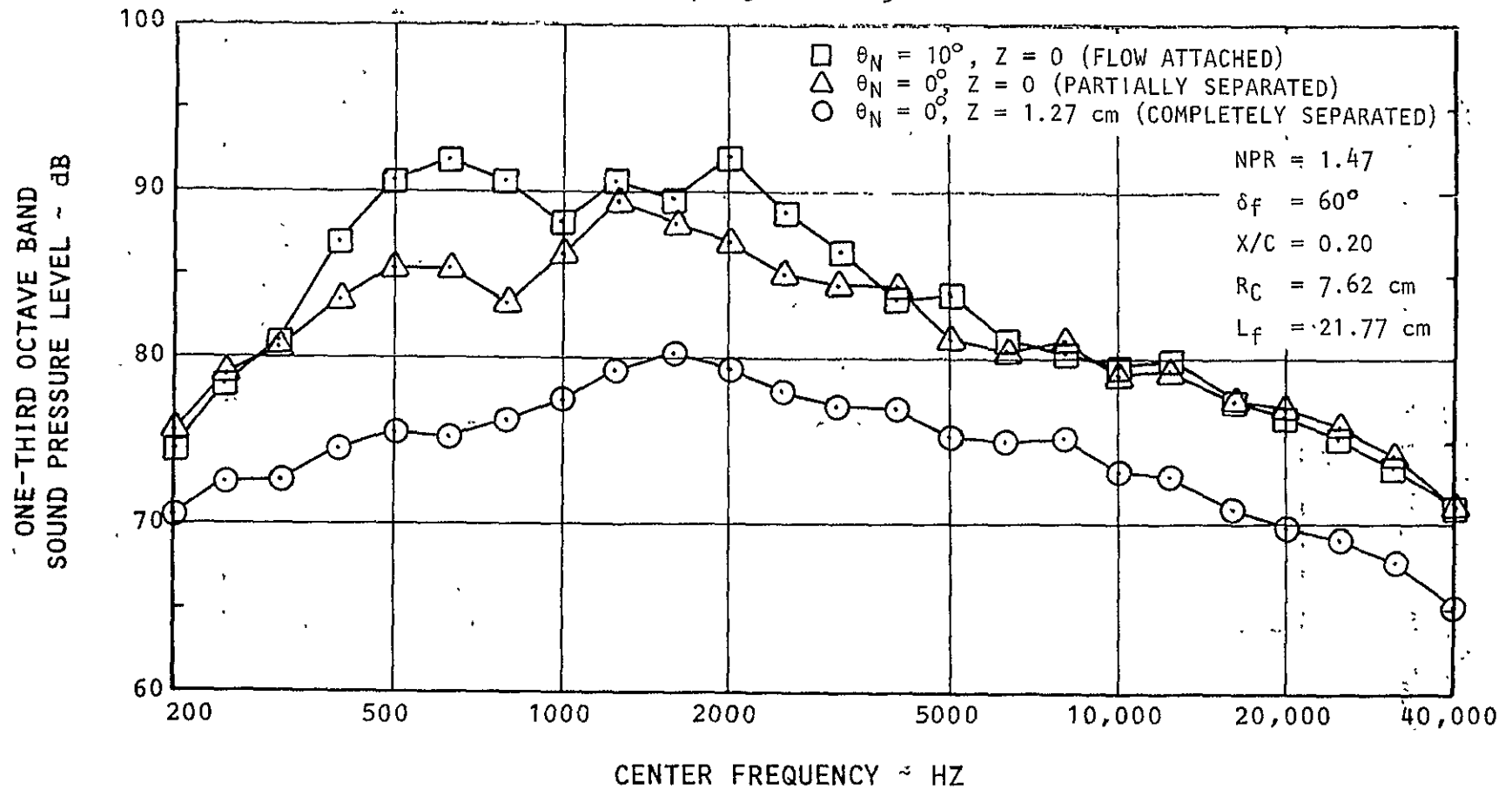


FIGURE 4-27. EFFECT OF FLOW SEPARATION ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

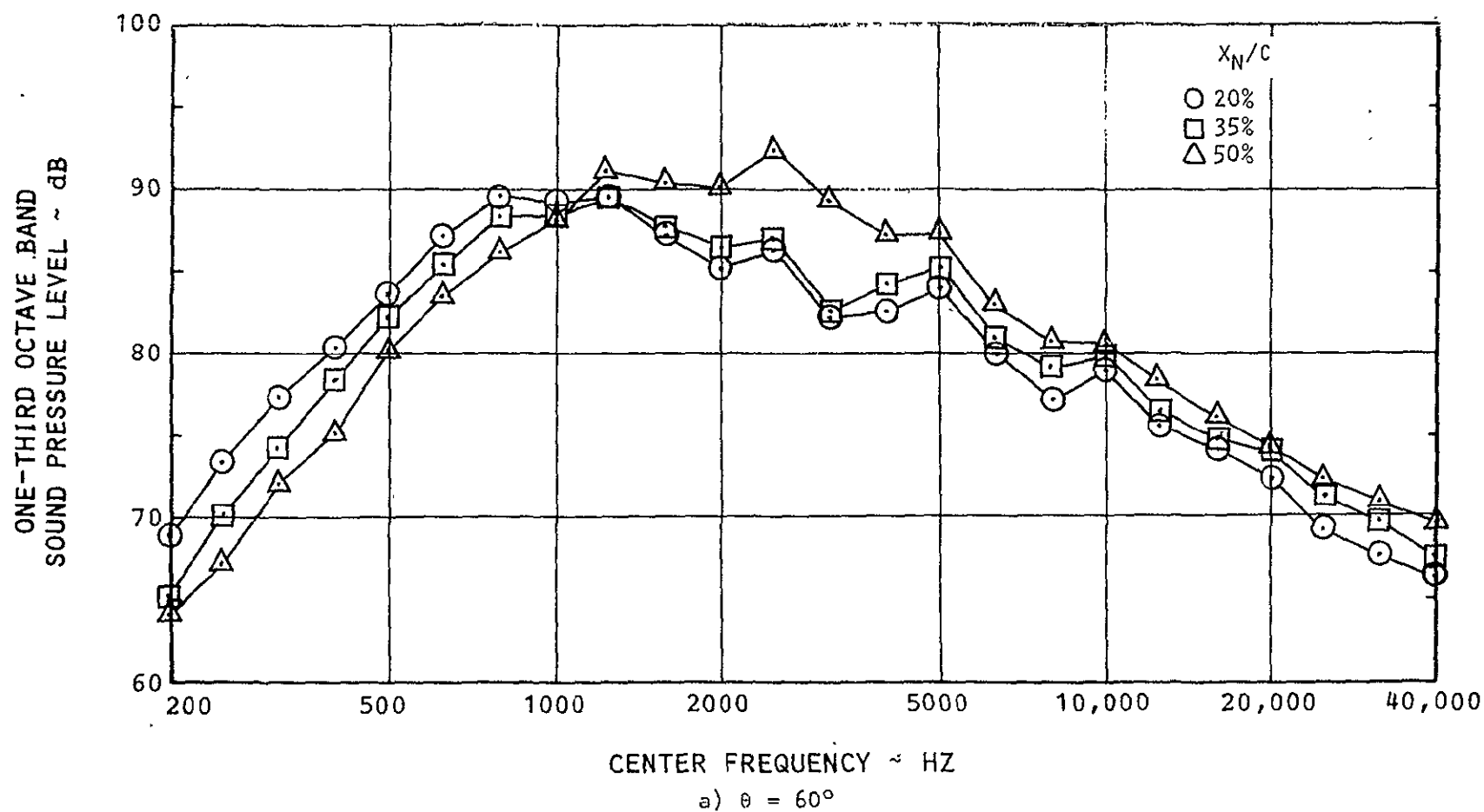
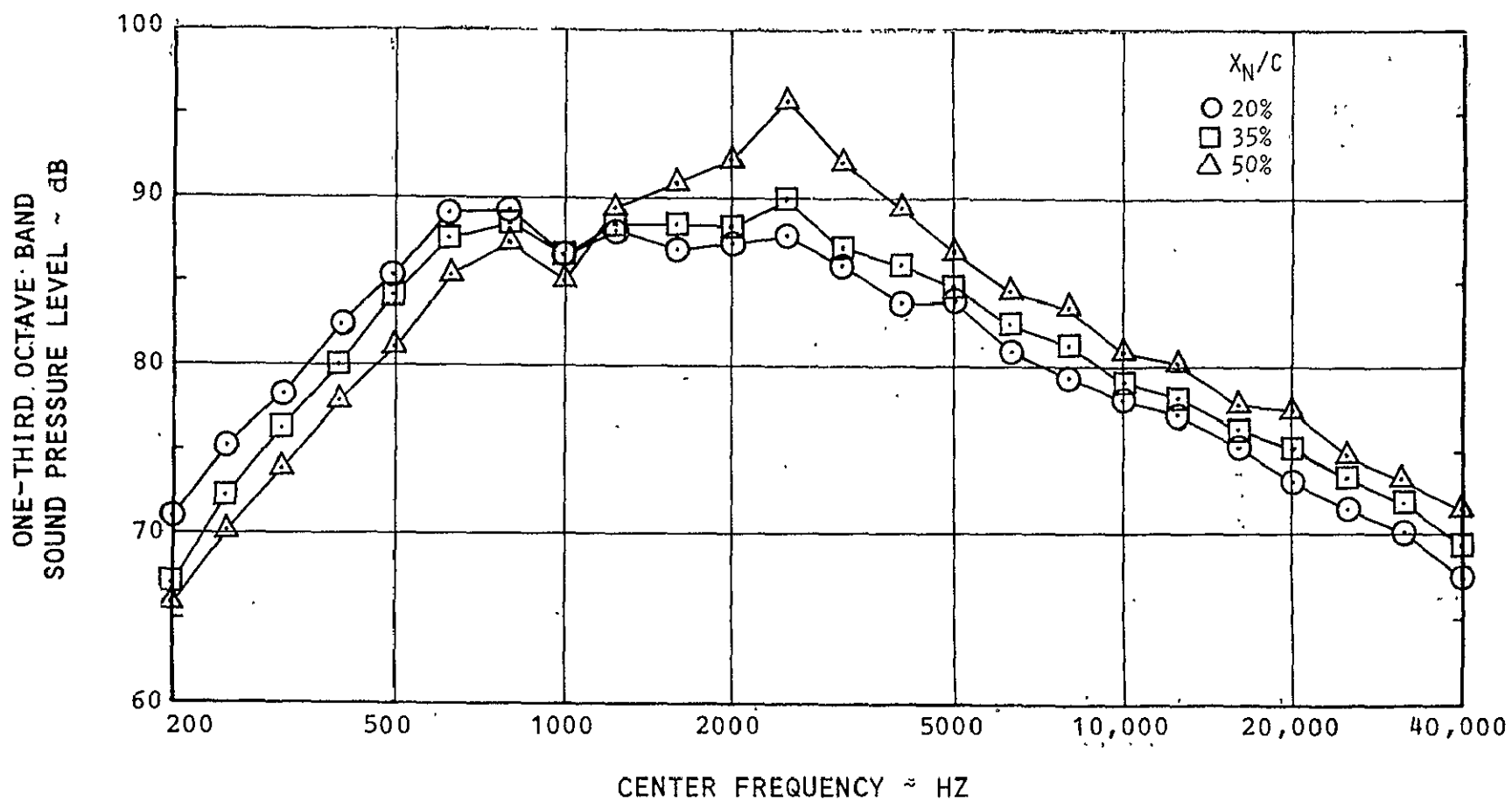


FIGURE 4-28. EFFECT OF NOZZLE CHORDWISE POSITION ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-28. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

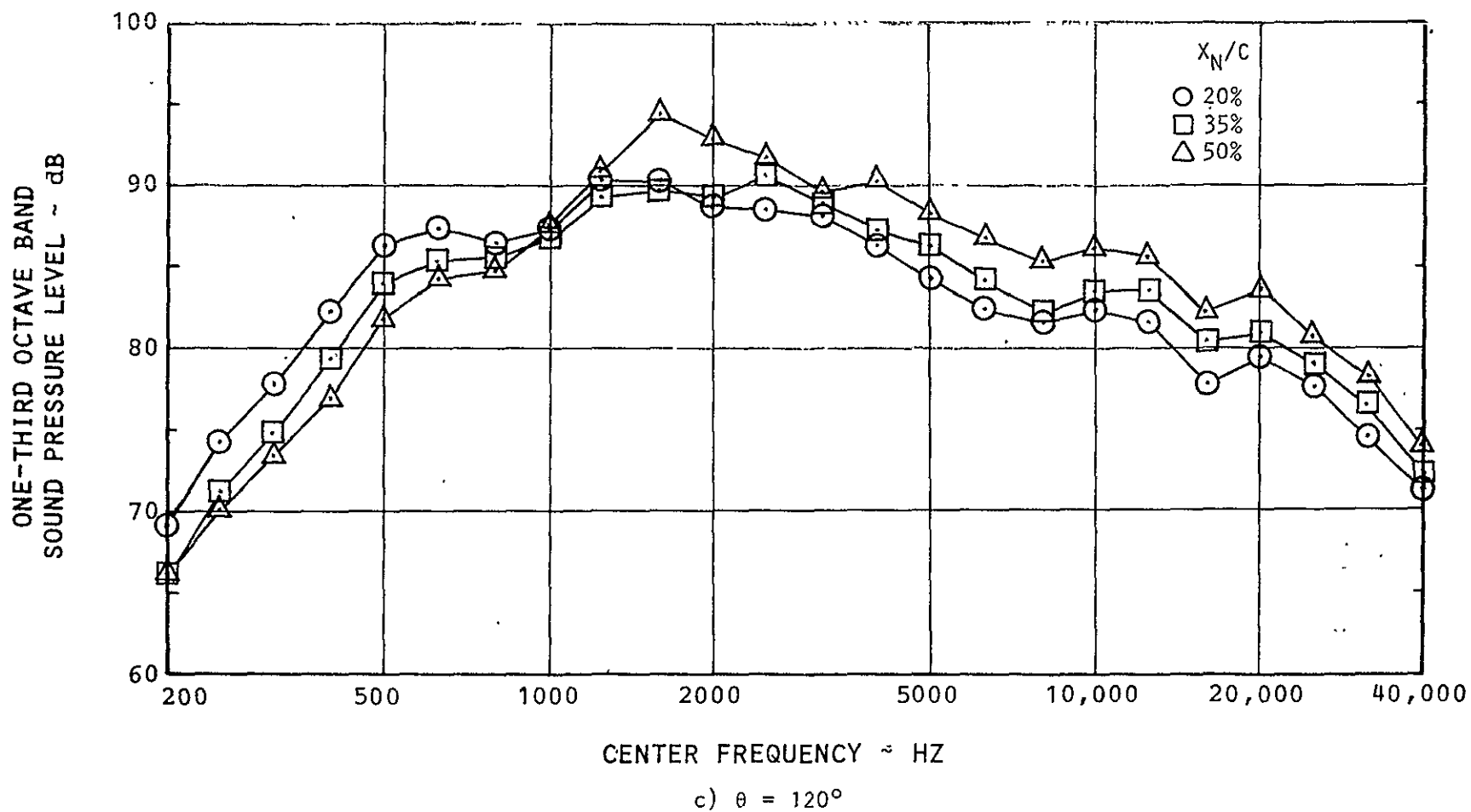


FIGURE 4-28. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS.

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

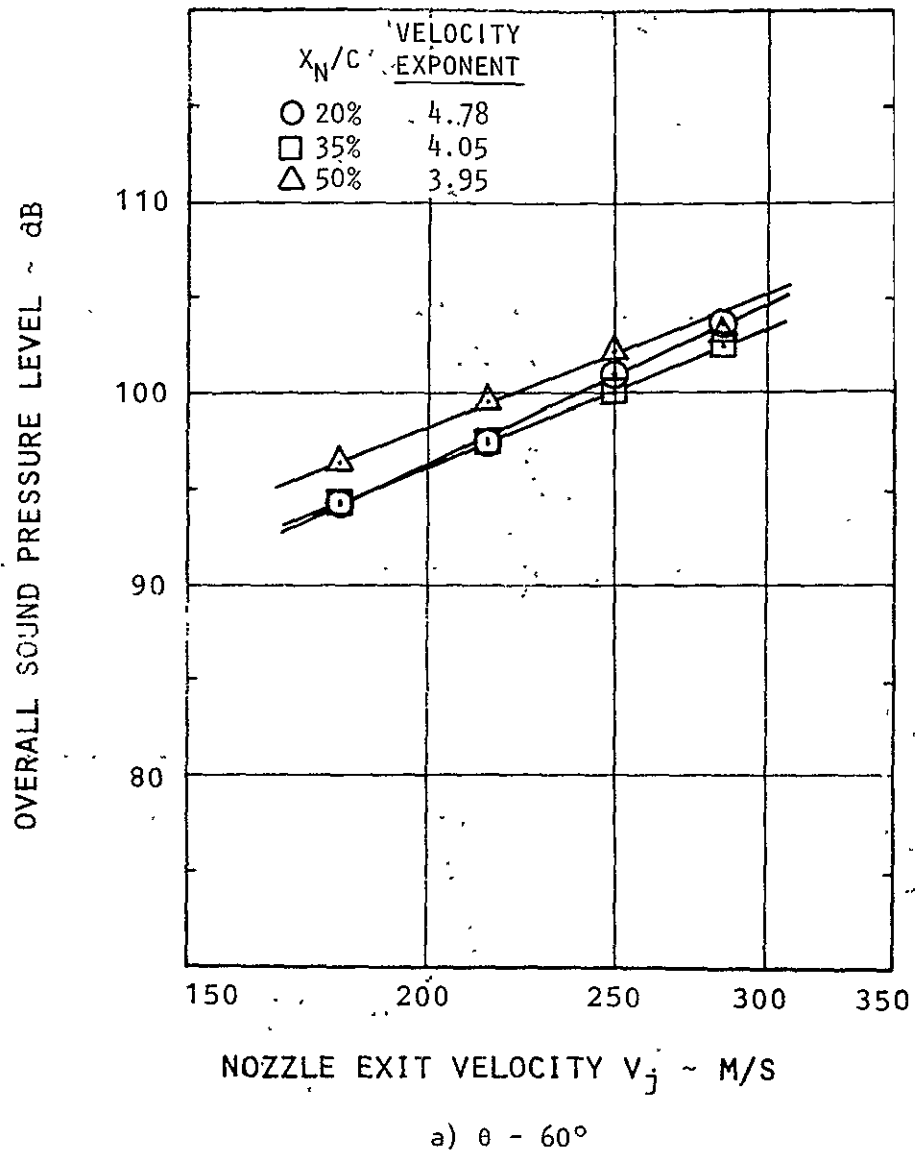


FIGURE 4-29. EFFECT OF NOZZLE CHORDWISE POSITION ON VELOCITY EXPONENT

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

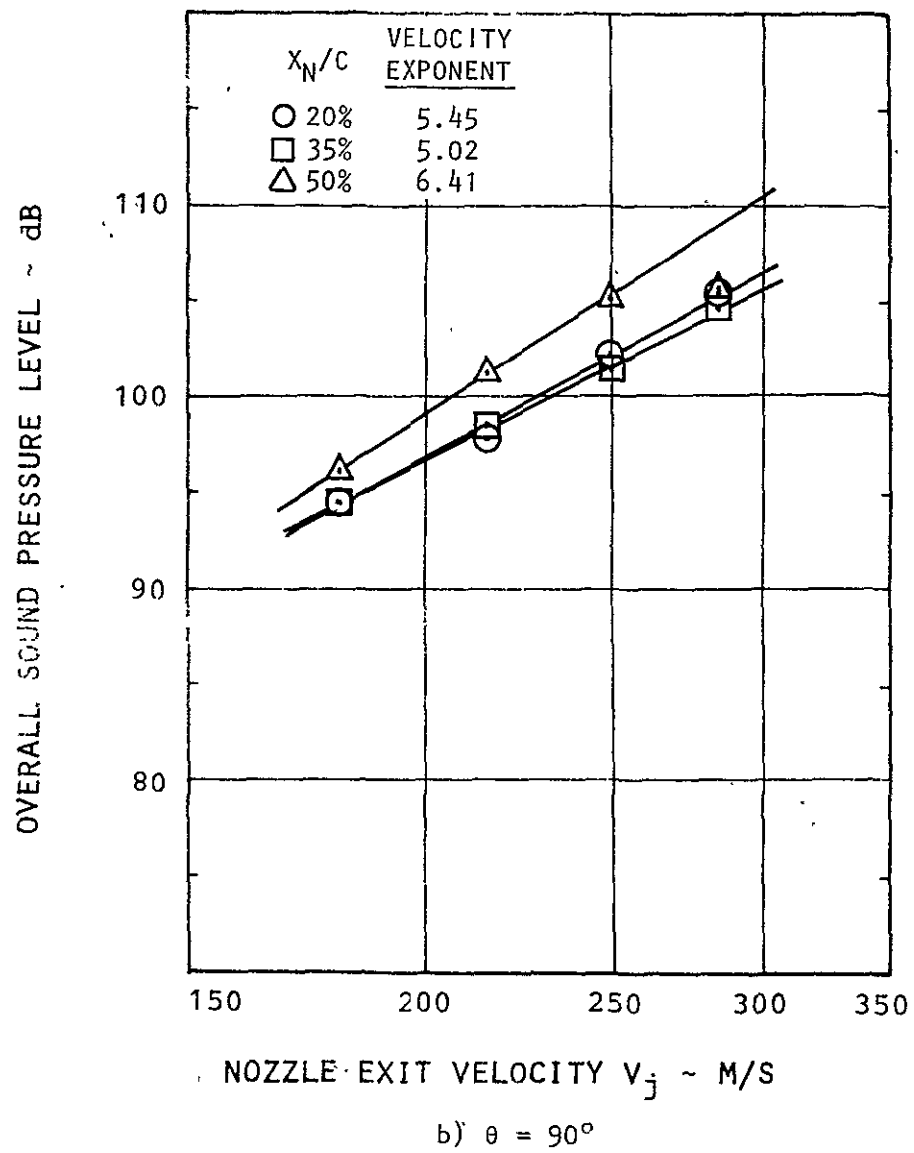
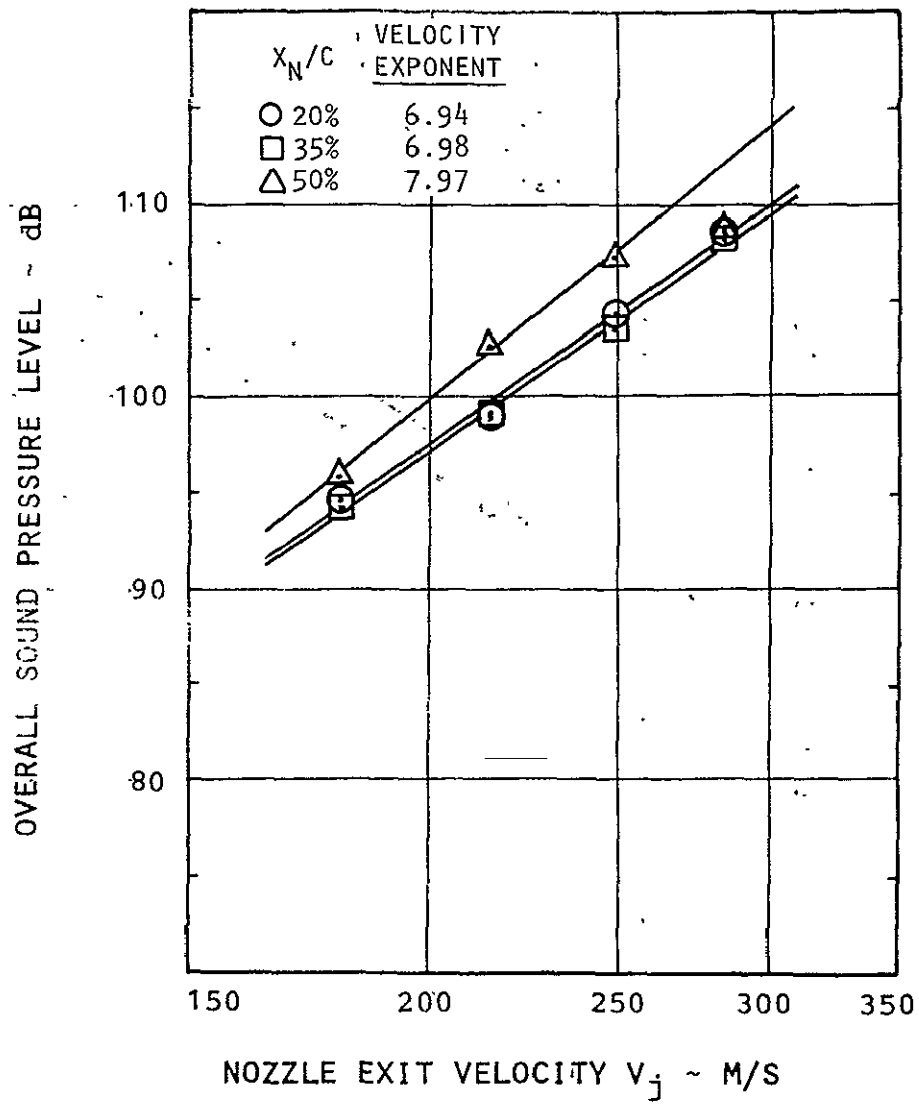


FIGURE 4-29. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-29. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

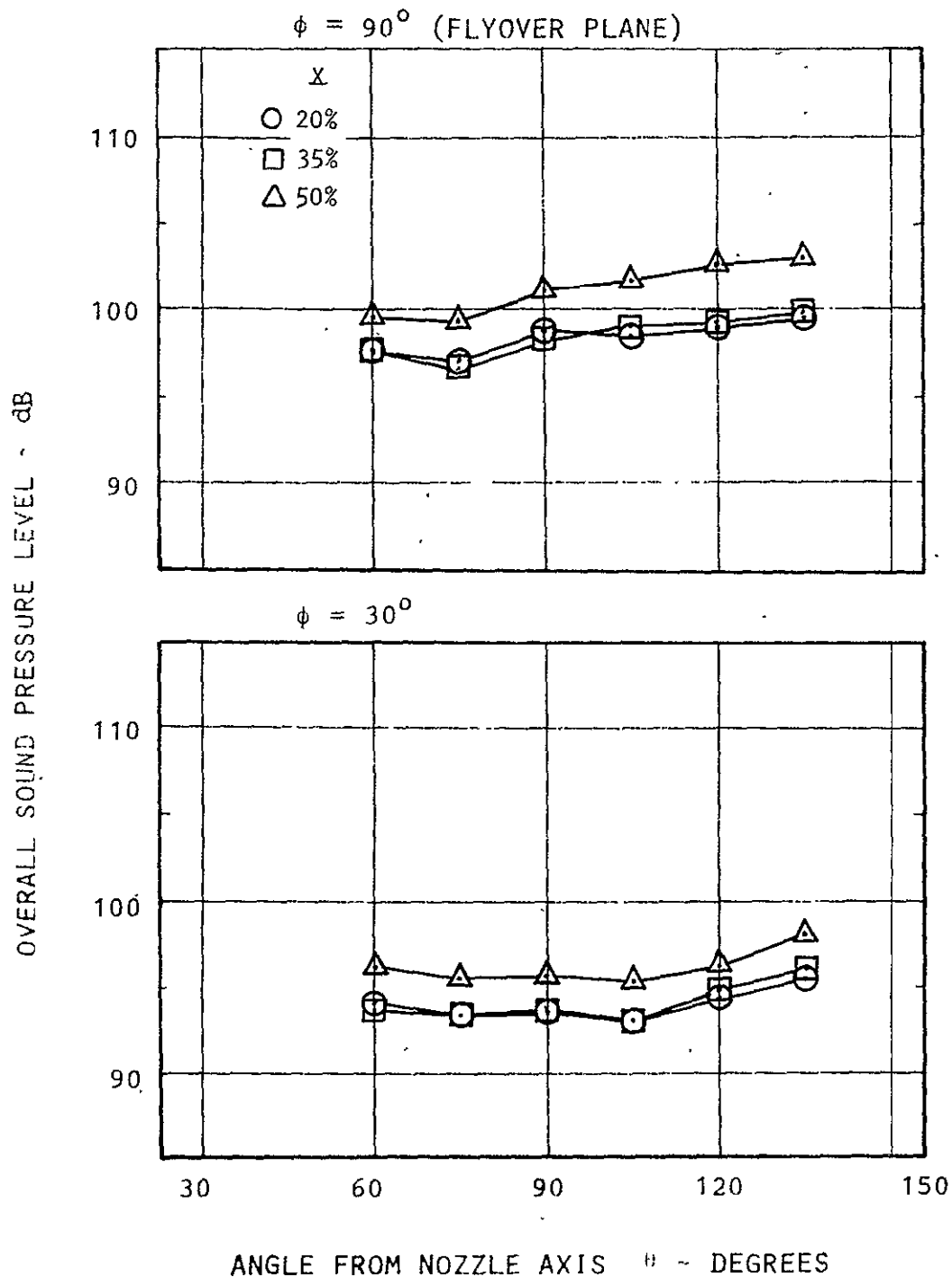


FIGURE 4-30. EFFECT OF NOZZLE CHORDWISE POSITION ON DIRECTIVITY

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

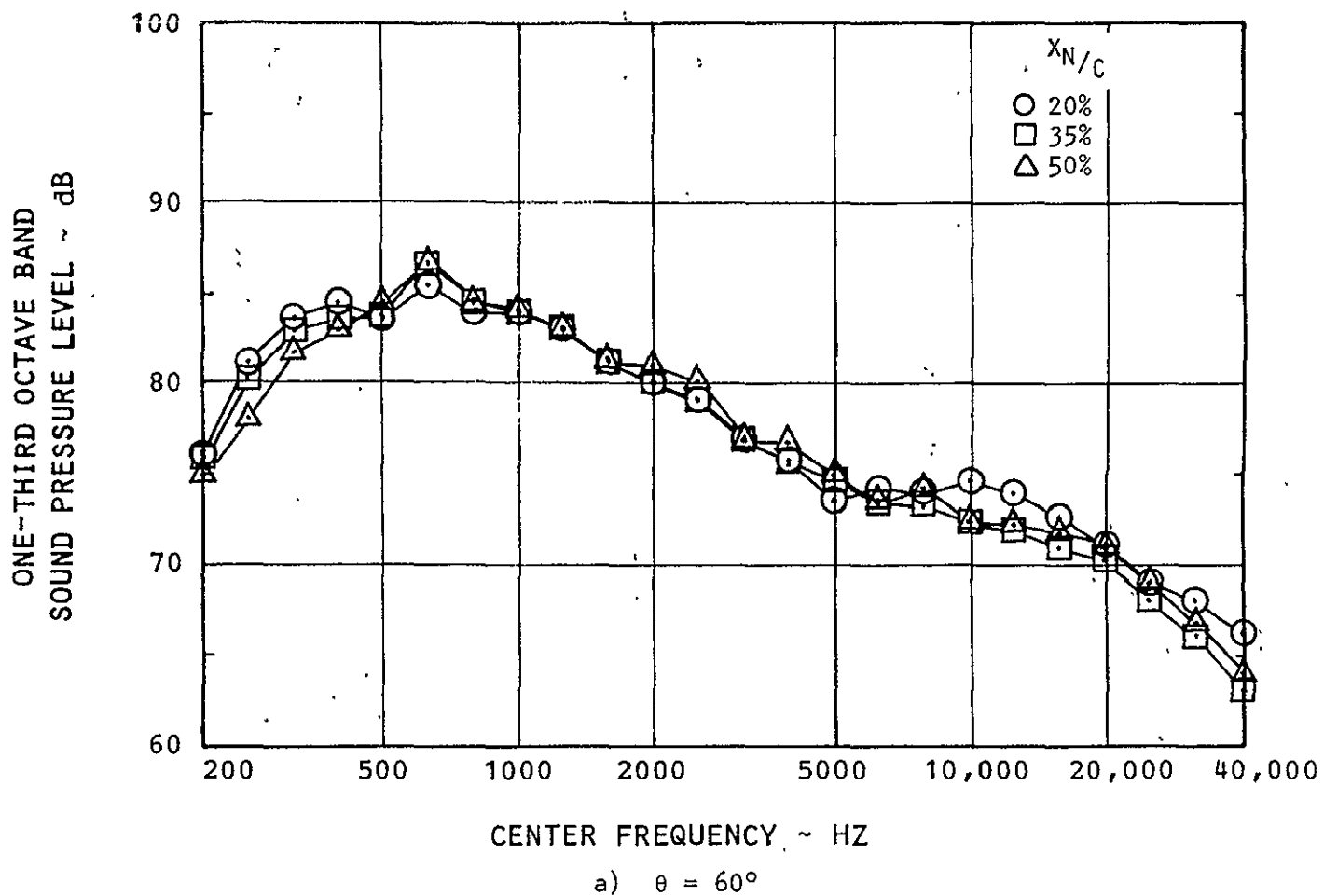
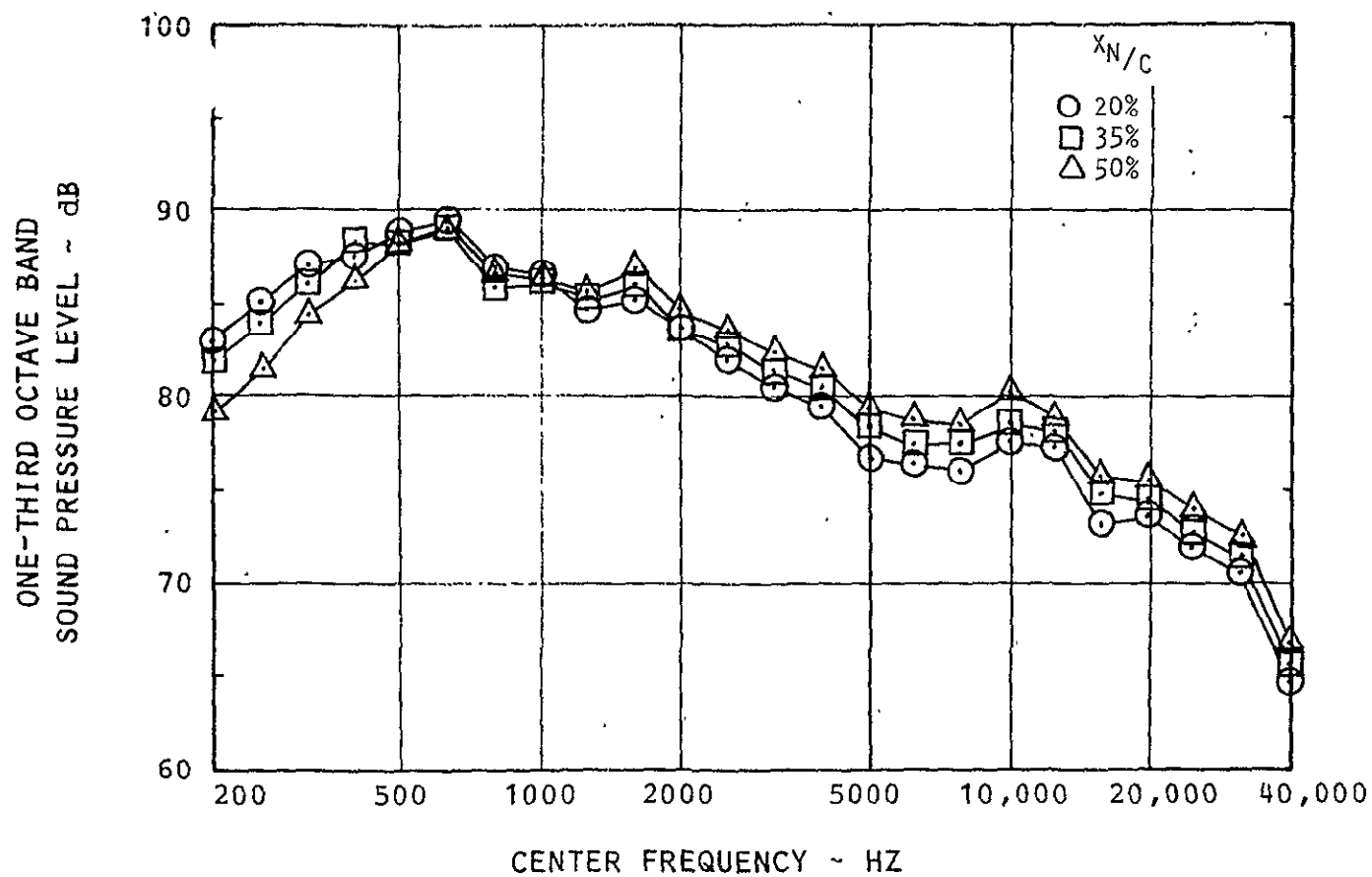


FIGURE 4-31. EFFECT OF NOZZLE CHORDWISE POSITION ON SPECTRUM

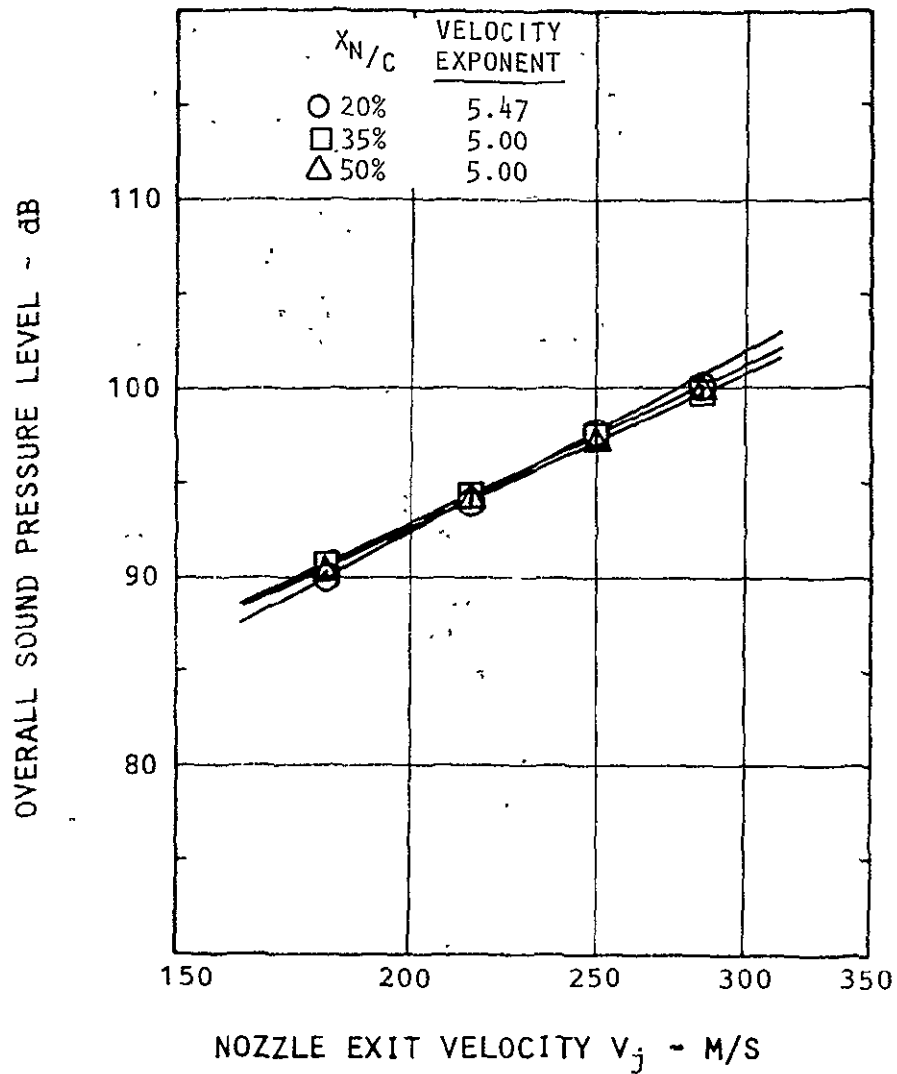
LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-31. (CONCLUDED)

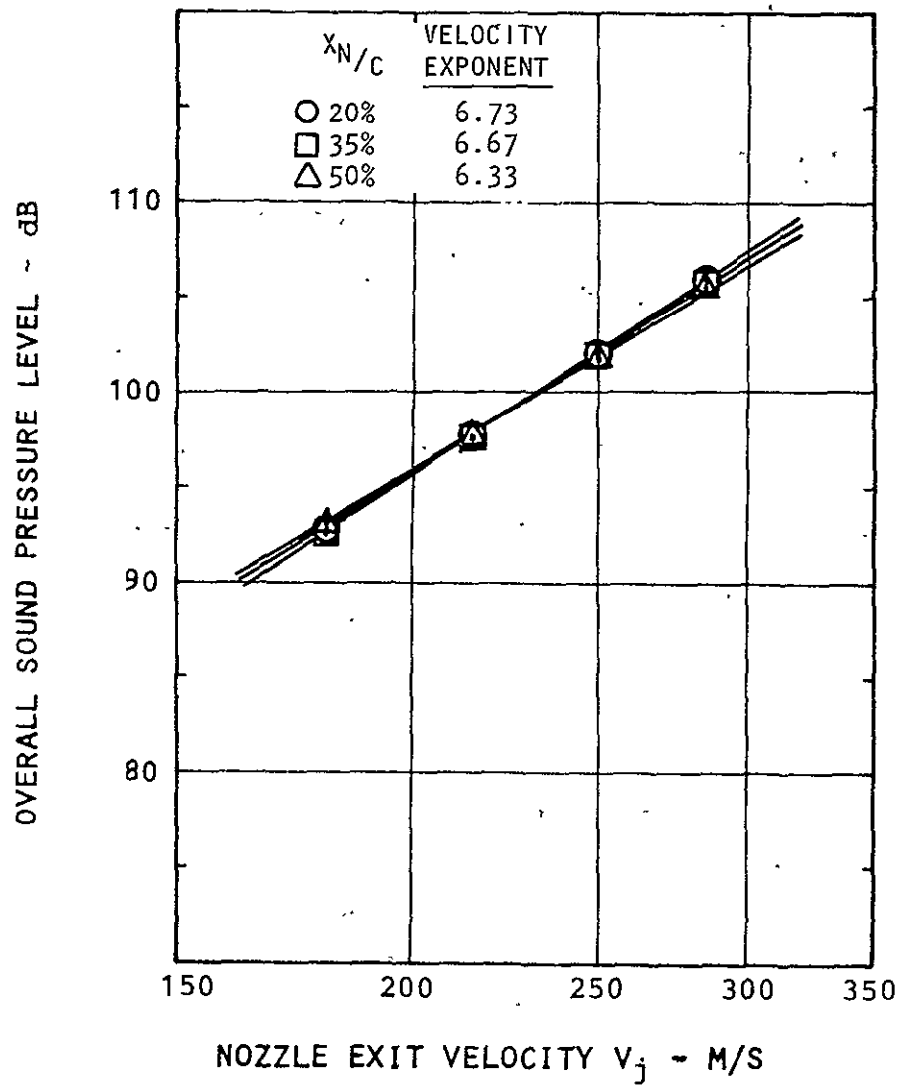
LARGE-SCALE MODEL AT 6.1 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-32. EFFECT OF NOZZLE CHORDWISE POSITION ON VELOCITY EXPONENT

LARGE-SCALE MODEL AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-32. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

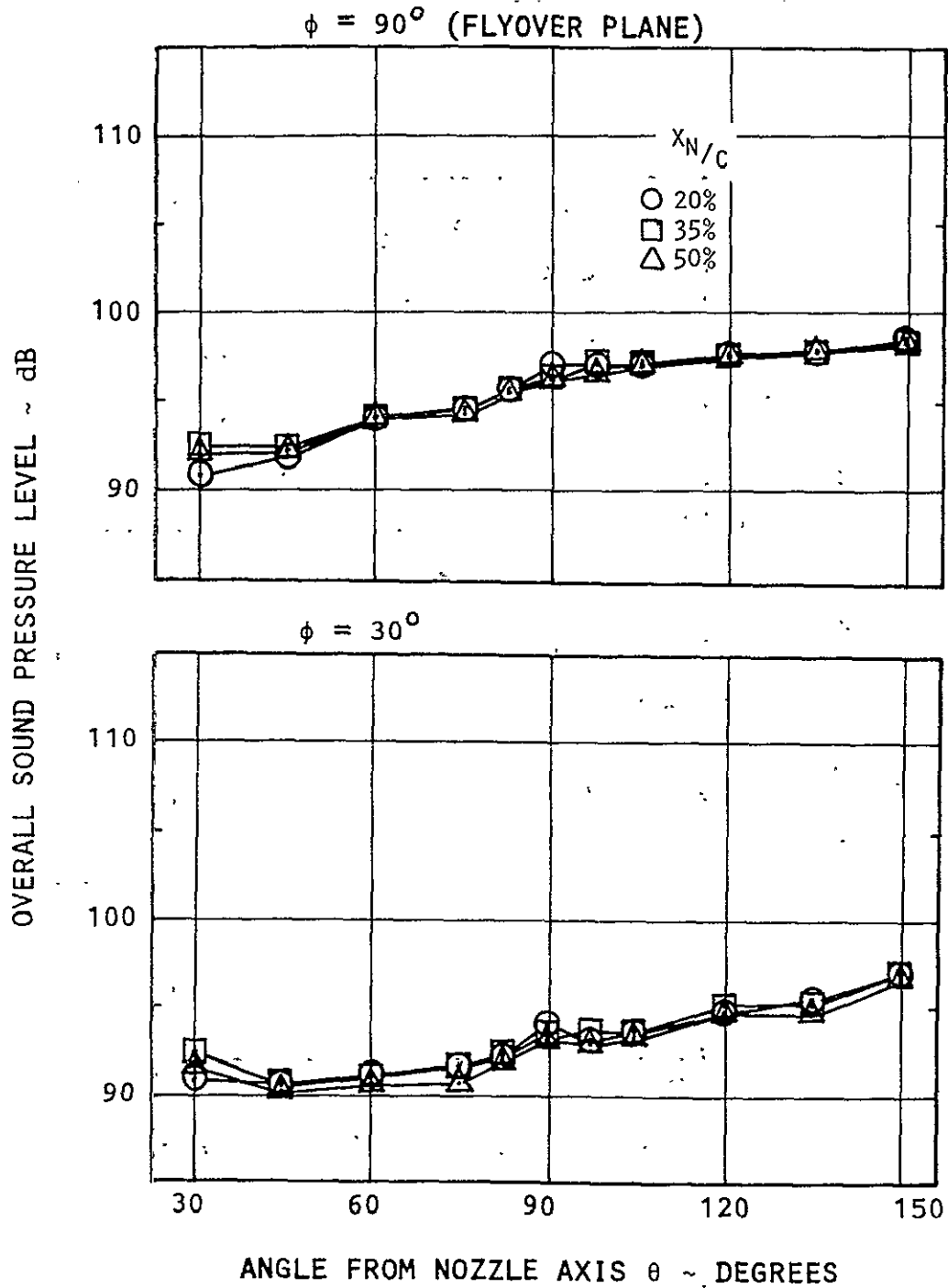


FIGURE 4-33. EFFECT OF NOZZLE CHORDWISE POSITION ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

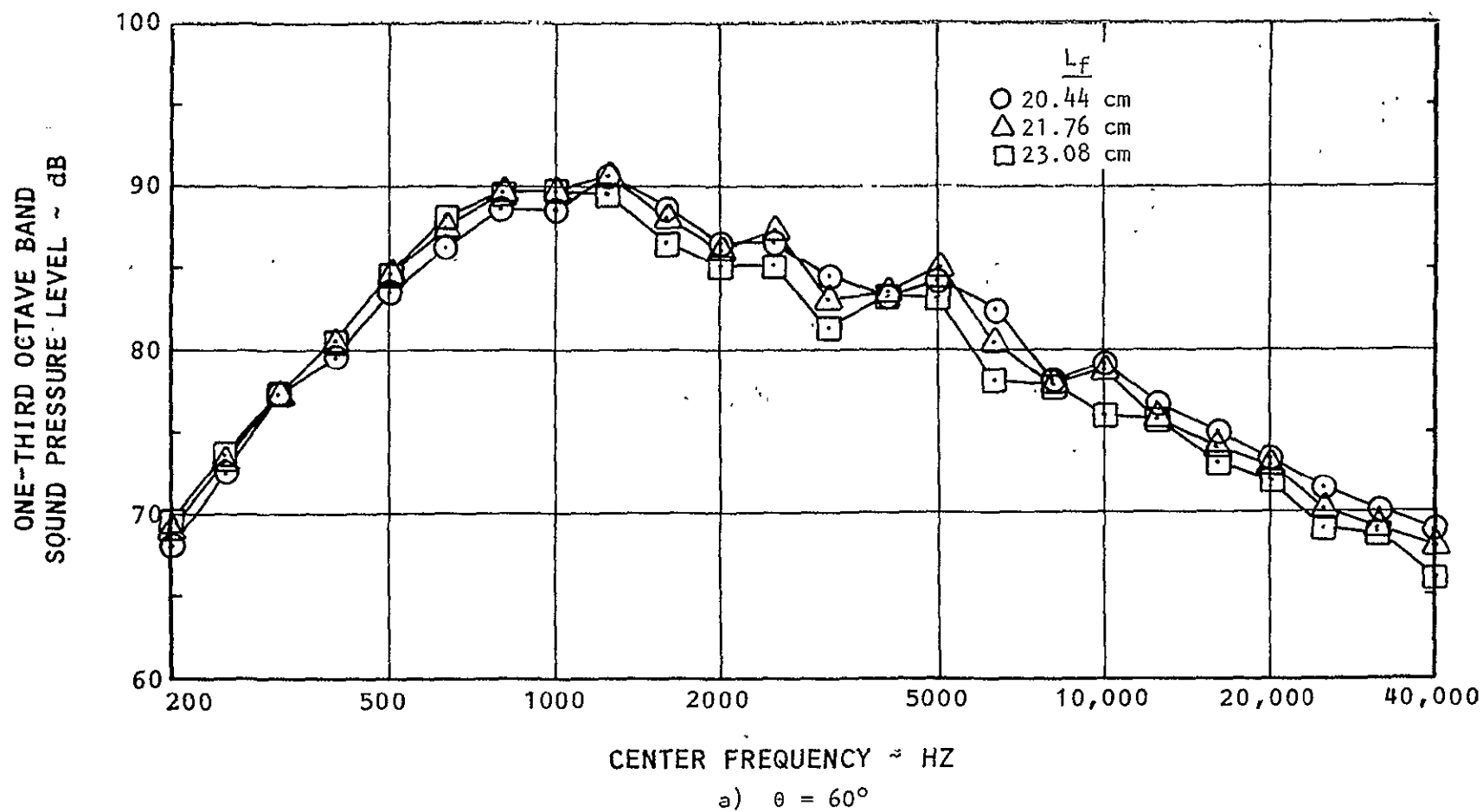


FIGURE 4-34. EFFECT OF FLAP LENGTH ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

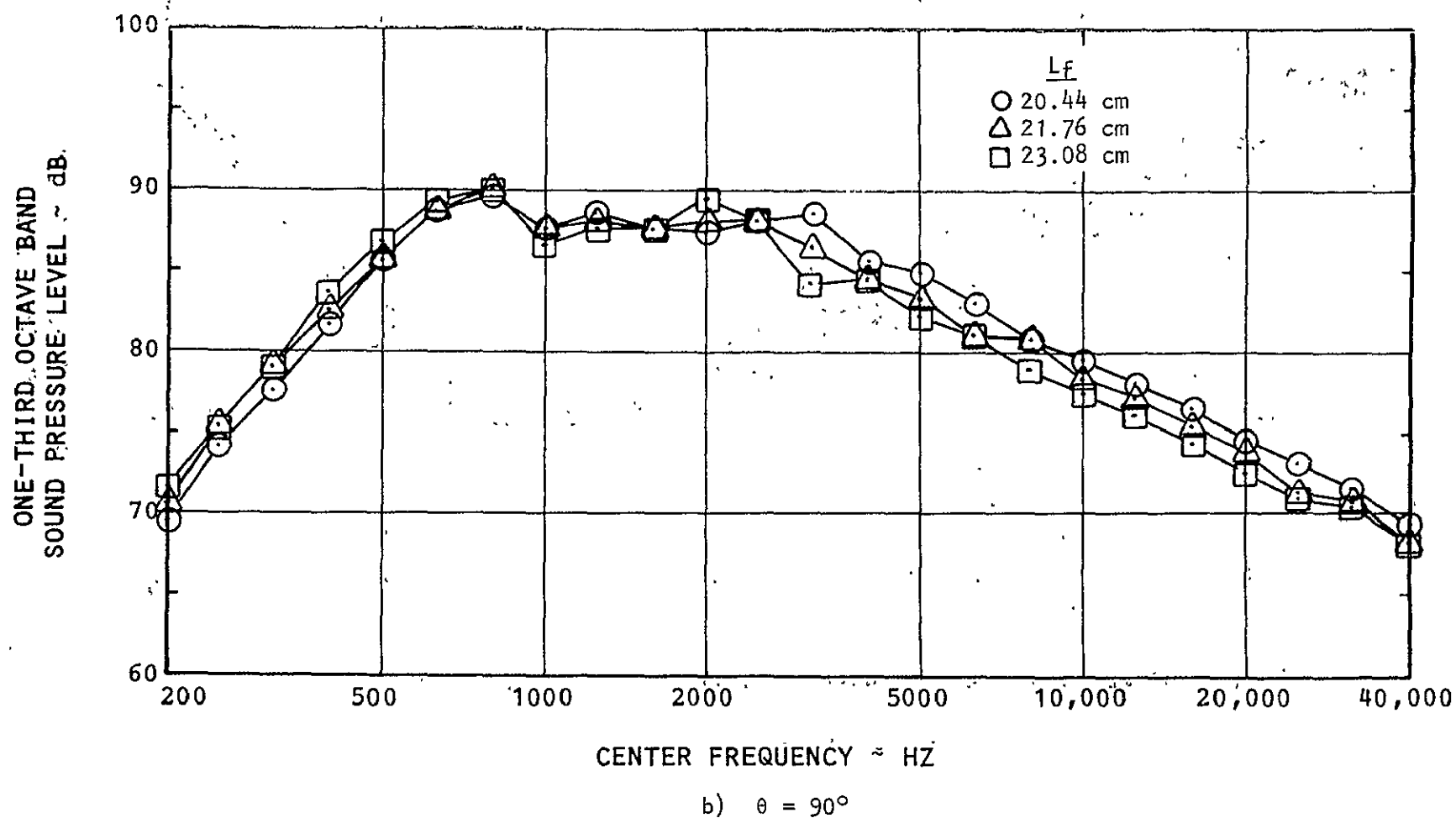


FIGURE 4-34. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

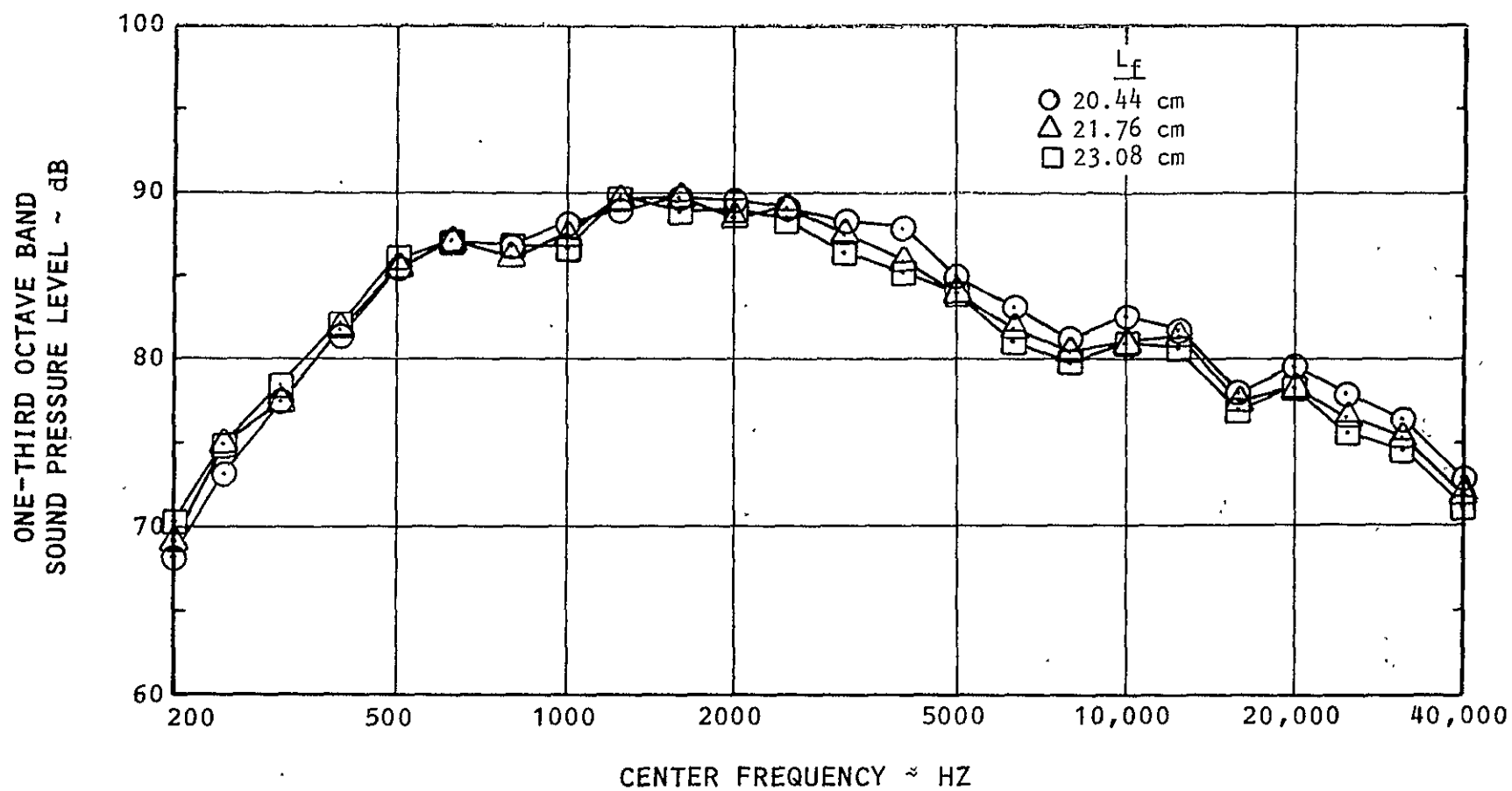
c) $\theta = 120^\circ$

FIGURE 4-34. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

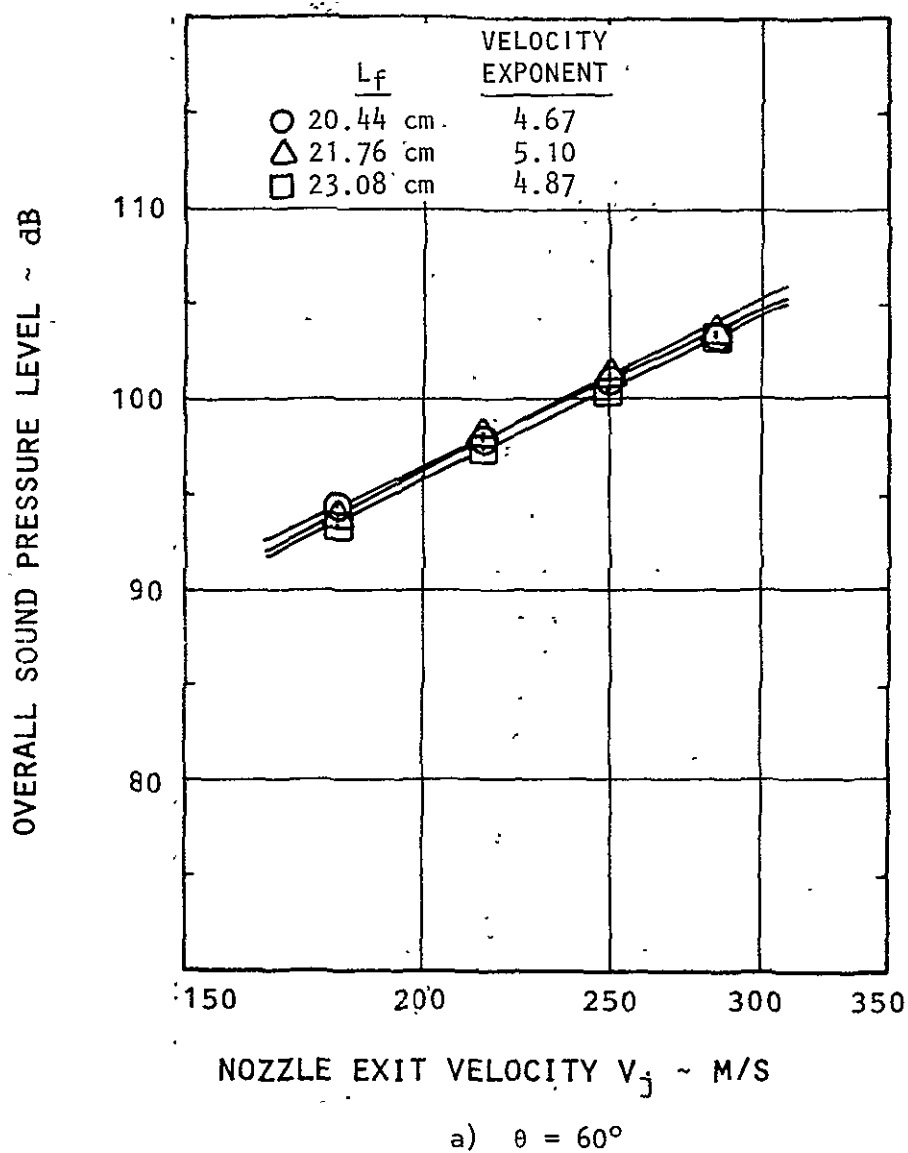
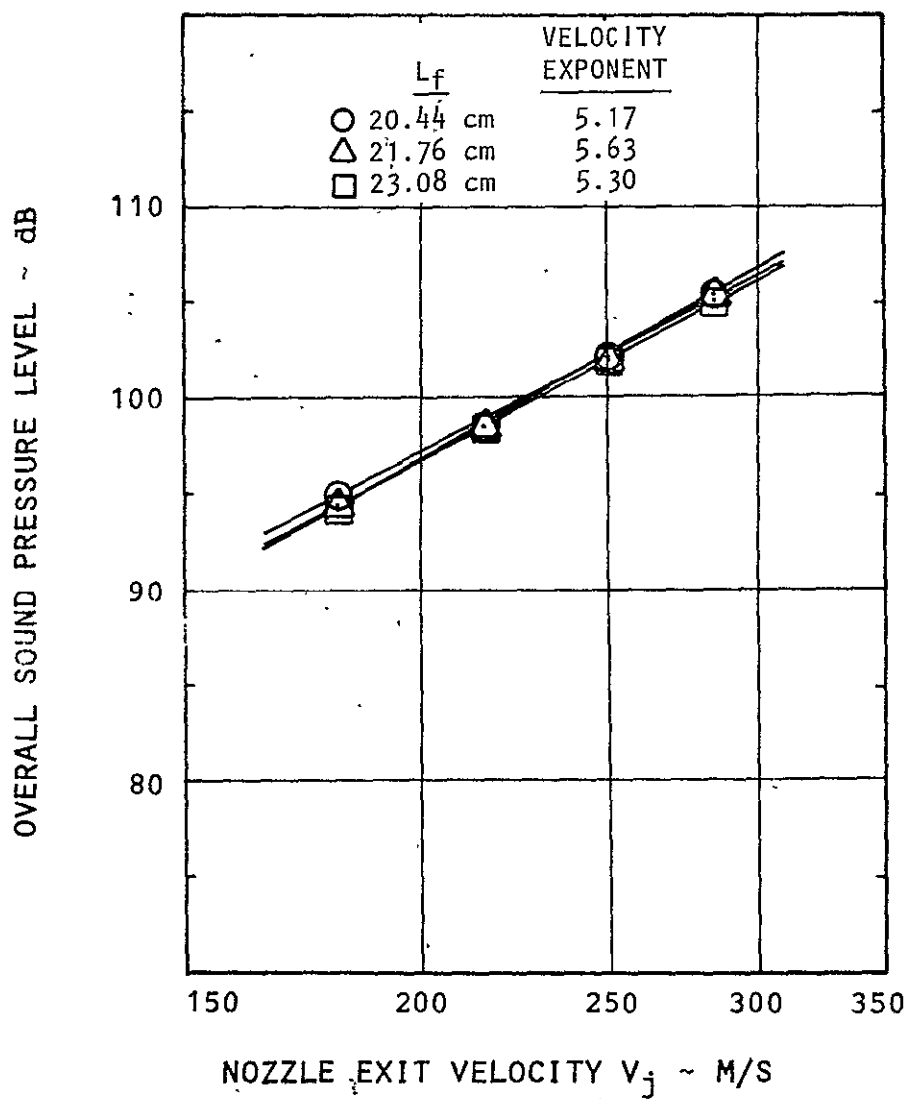


FIGURE 4-35. EFFECT OF FLAP LENGTH ON VELOCITY EXPONENT

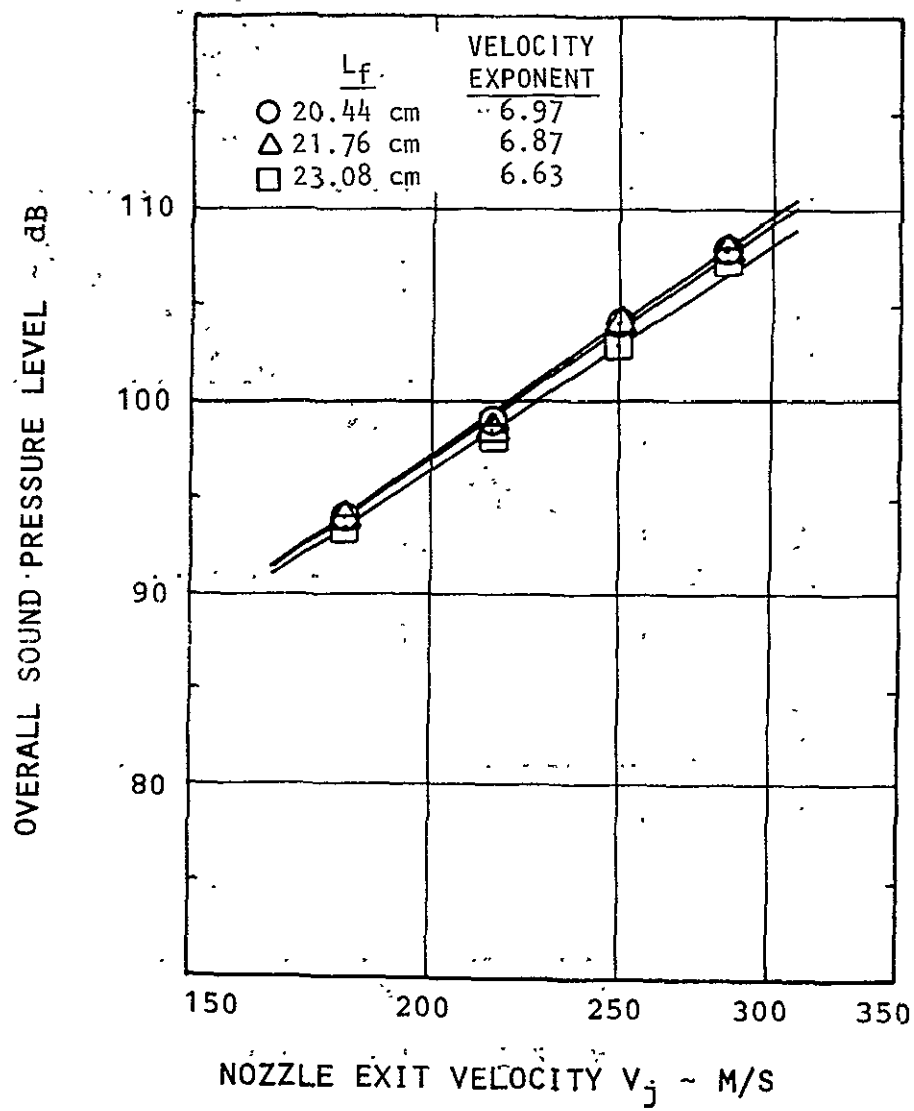
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-35. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-35. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

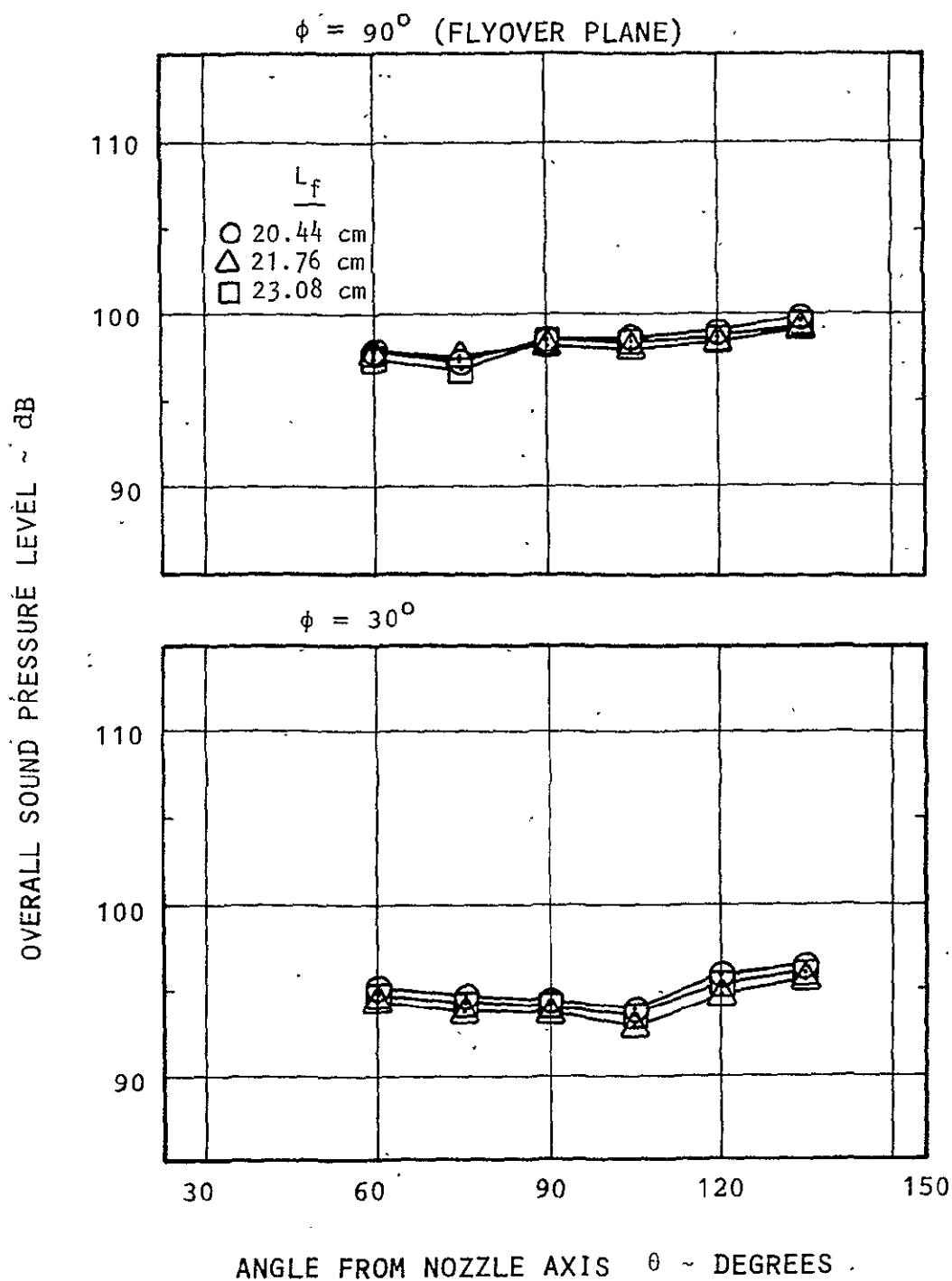


FIGURE 4-36. EFFECT OF FLAP LENGTH ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

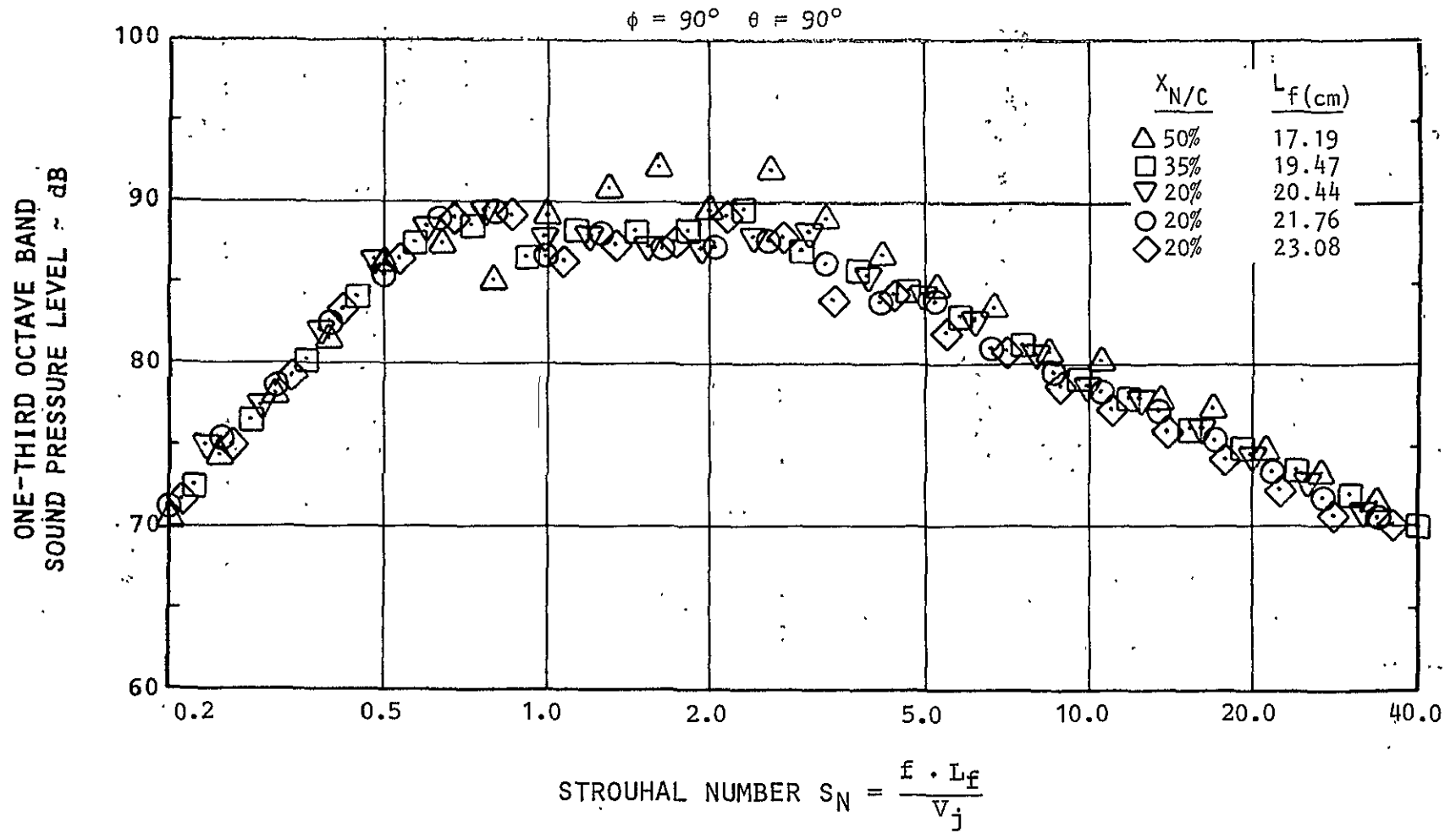
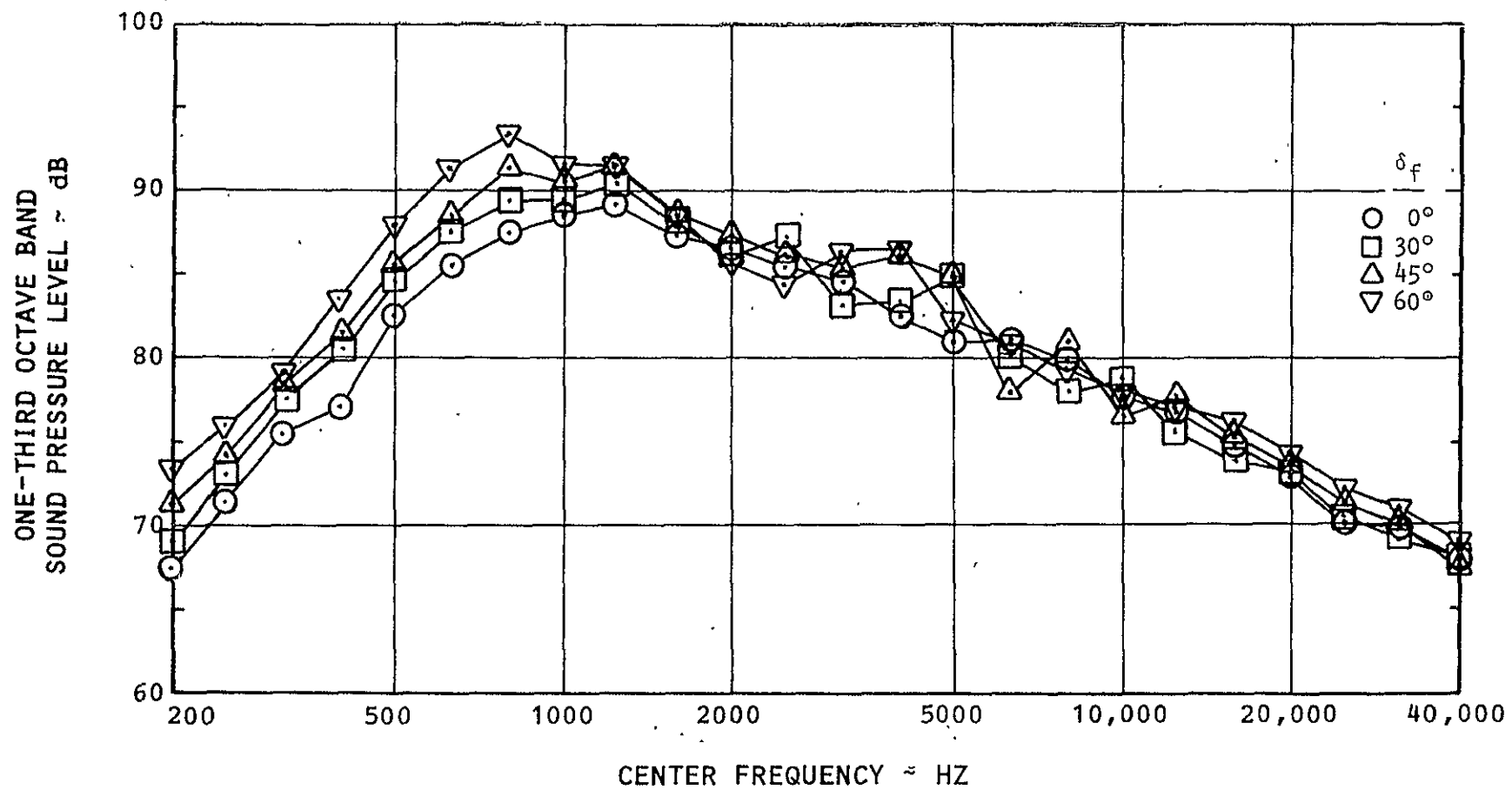


FIGURE 4-37. EFFECT OF FLOW PATH LENGTH ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-38. EFFECT OF FLAP ANGLE ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

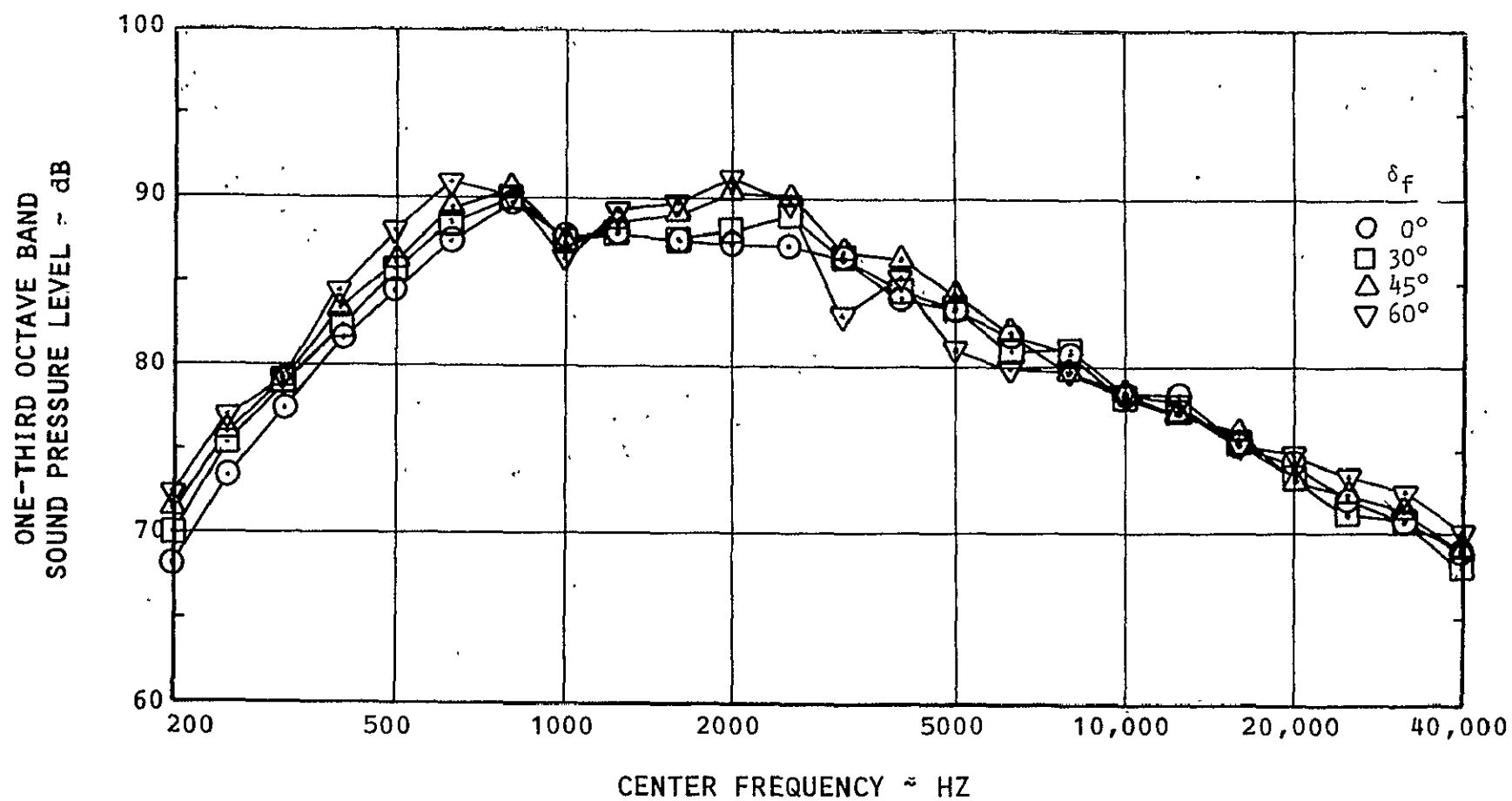
b) $\theta = 90^\circ$

FIGURE 4-38. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

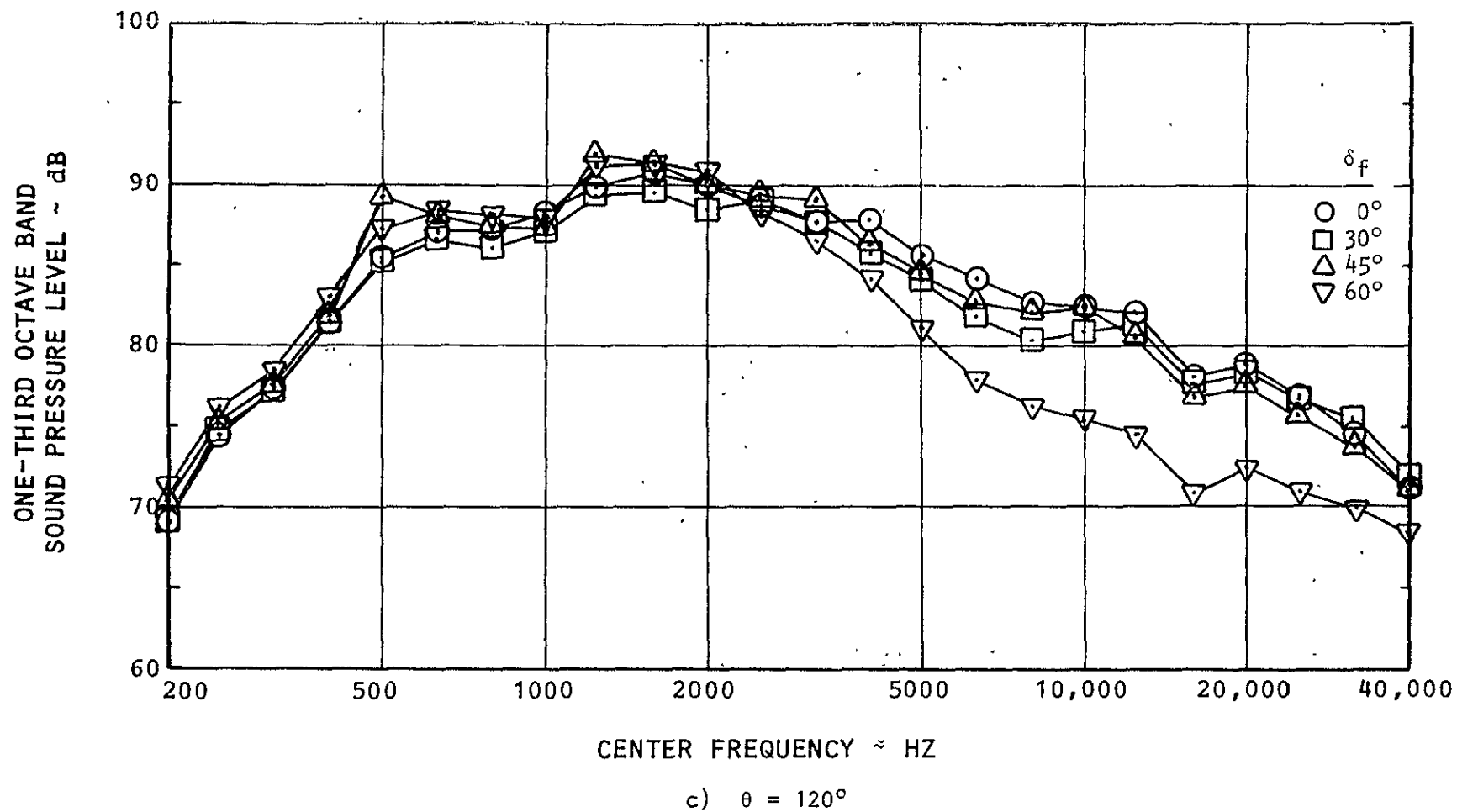
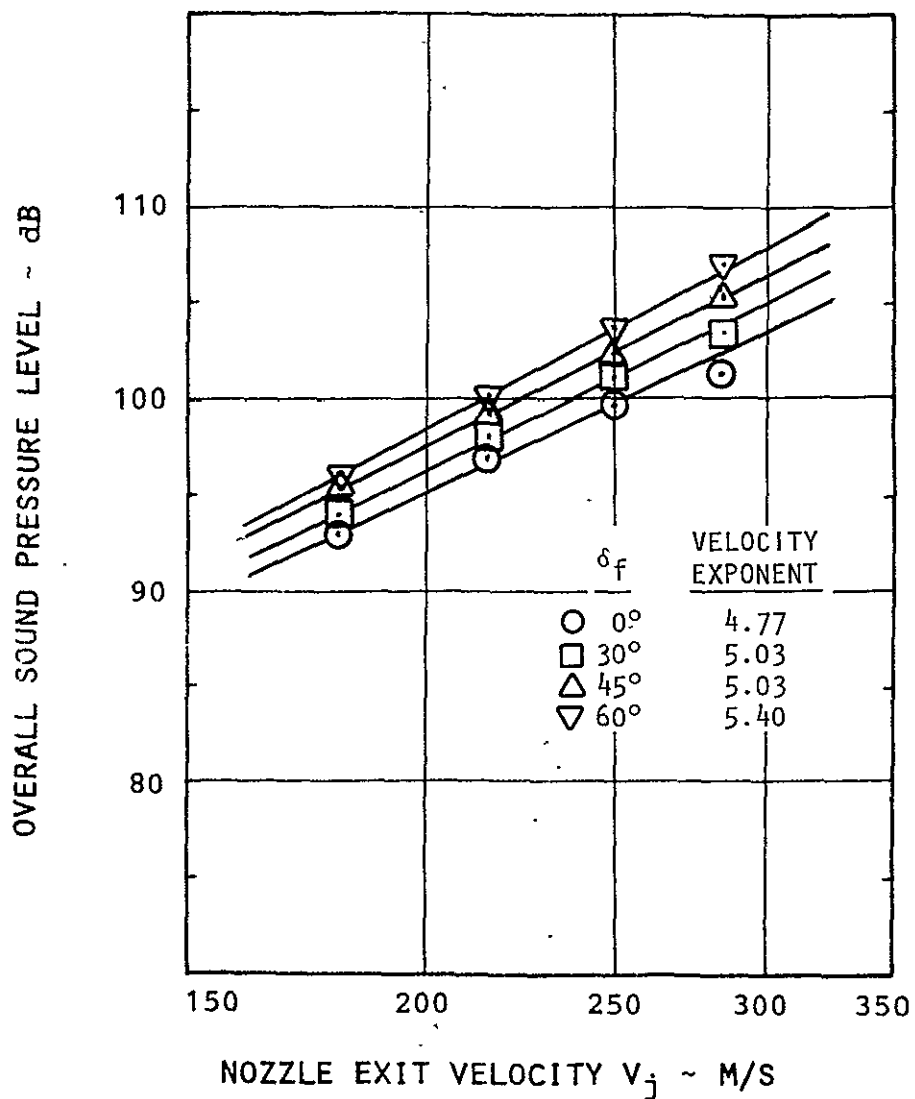


FIGURE 4-38. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

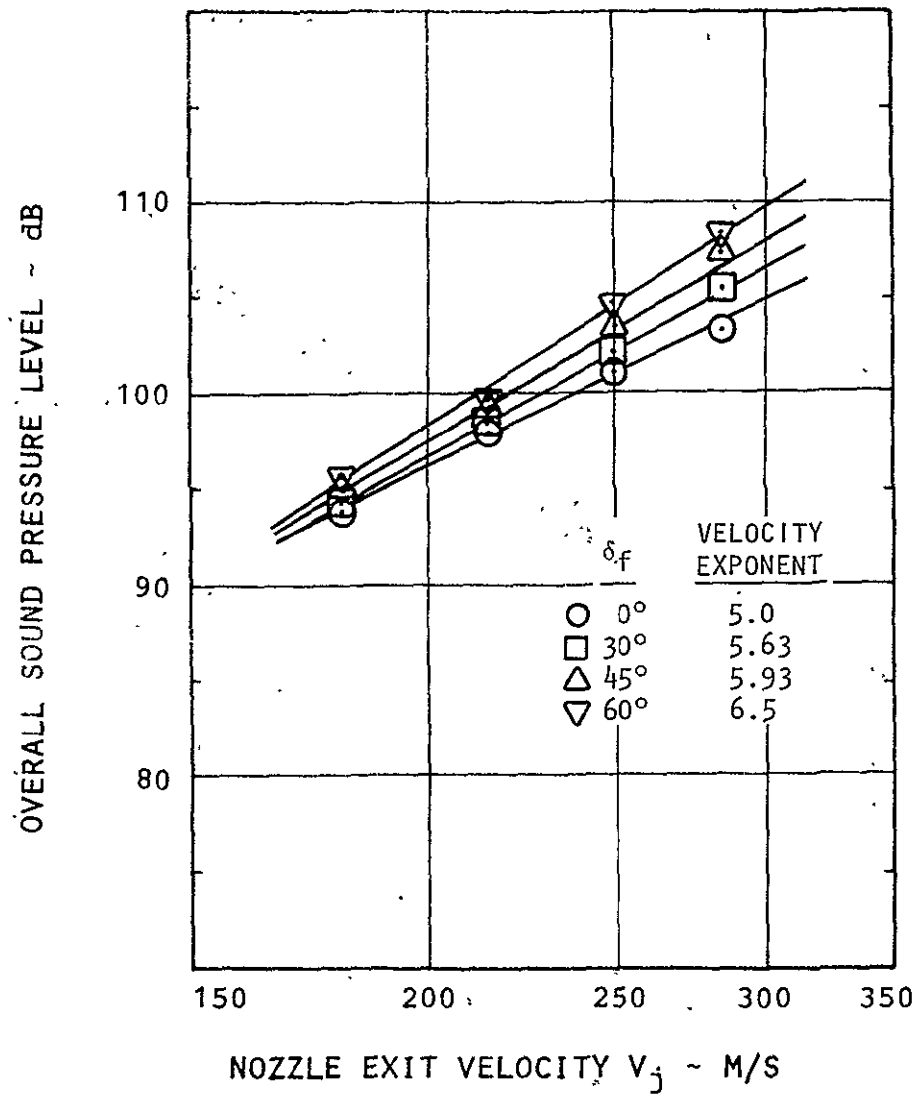
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-39. EFFECT OF FLAP ANGLE ON VELOCITY EXPONENT

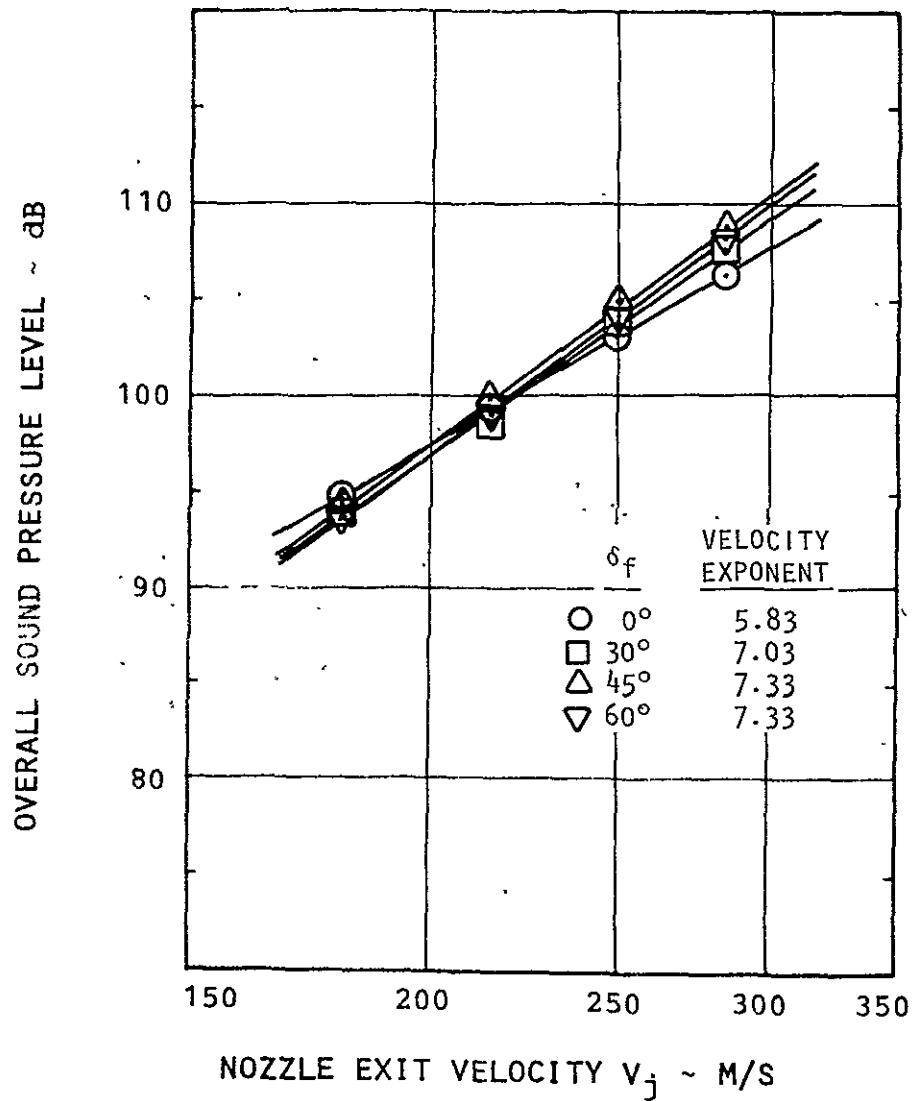
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-39. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-39. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

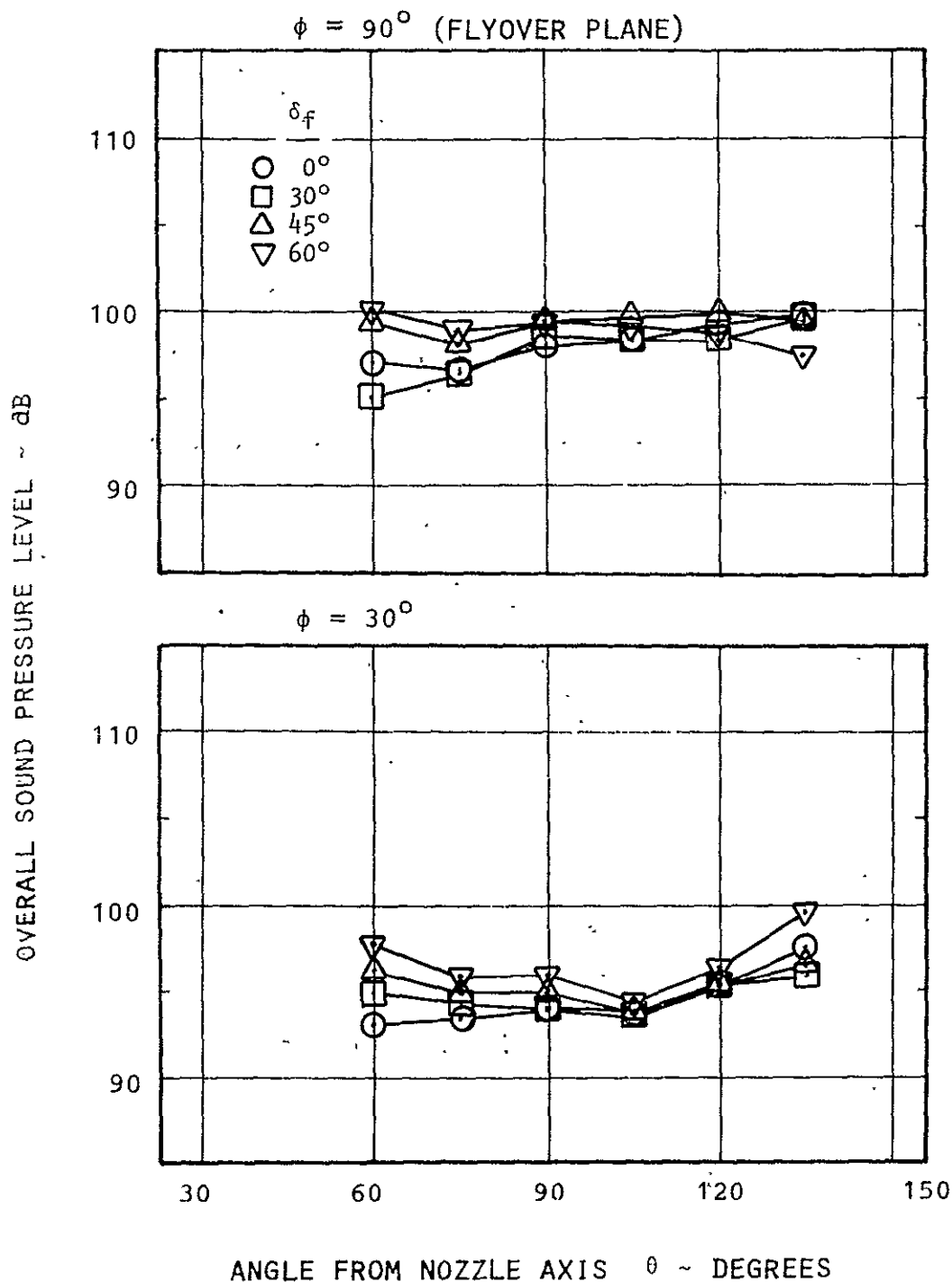


FIGURE 4-40. EFFECT OF FLAP ANGLE ON DIRECTIVITY

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

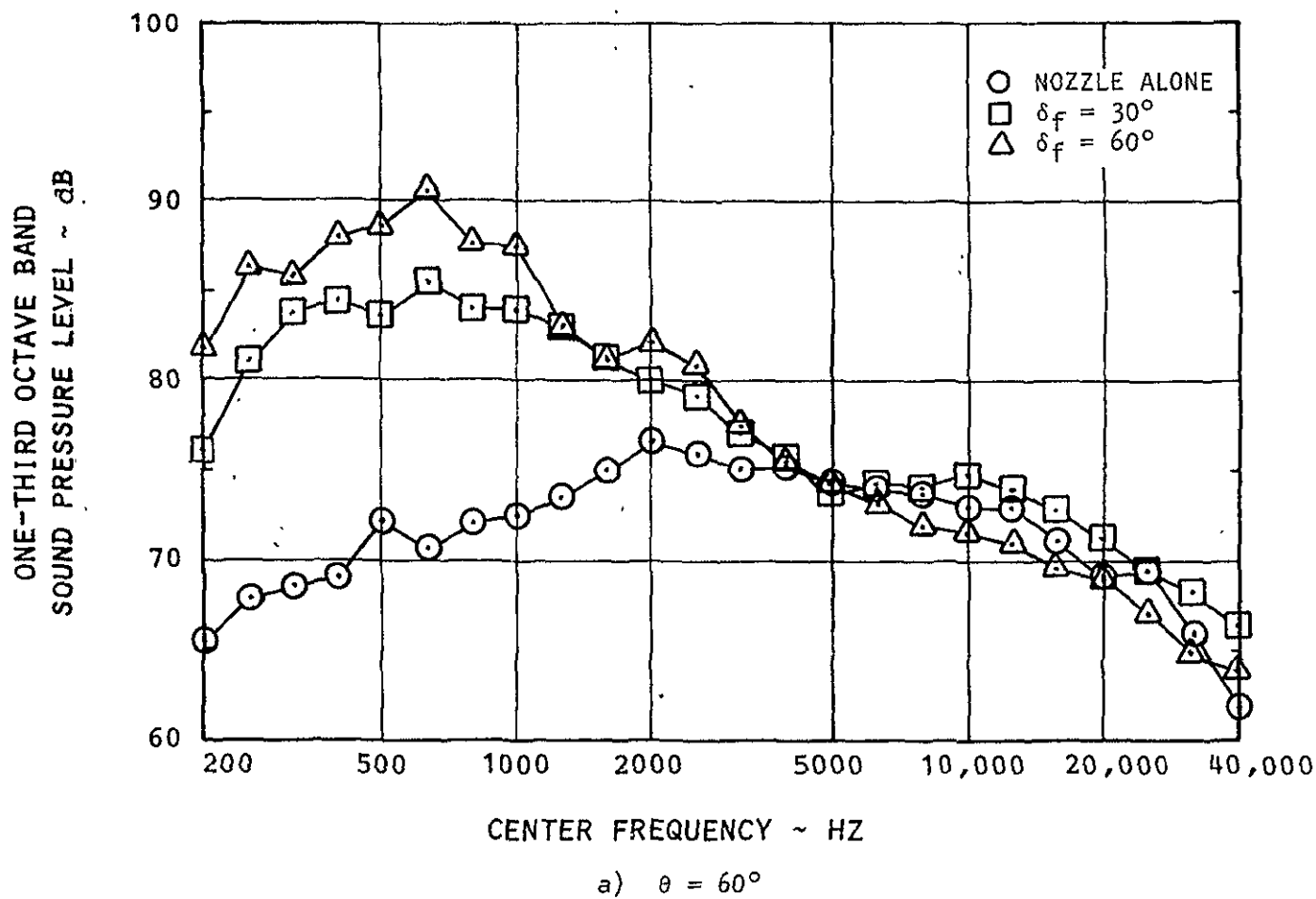


FIGURE 4-41. EFFECT OF FLAP ANGLE ON SPECTRUM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

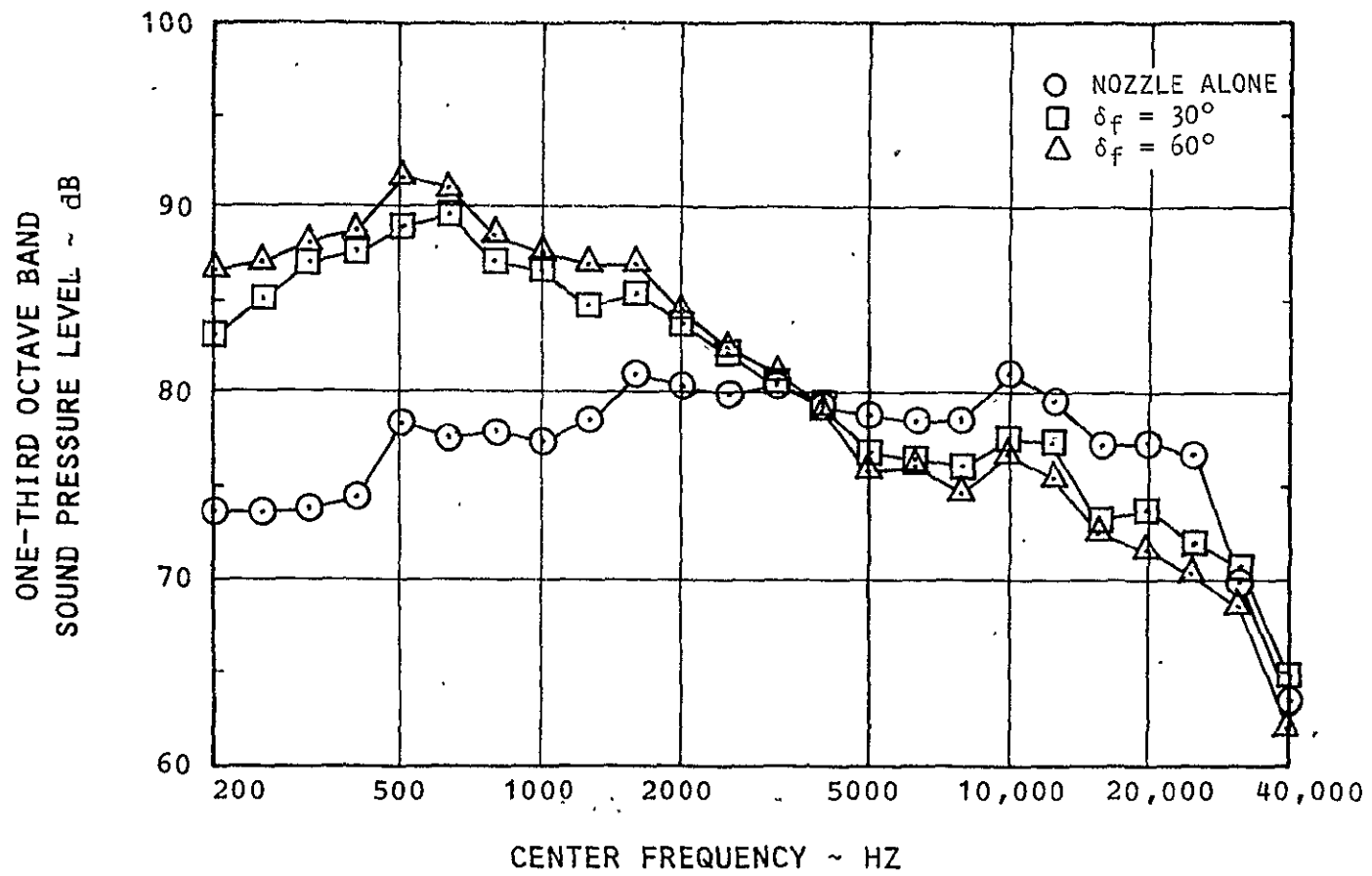
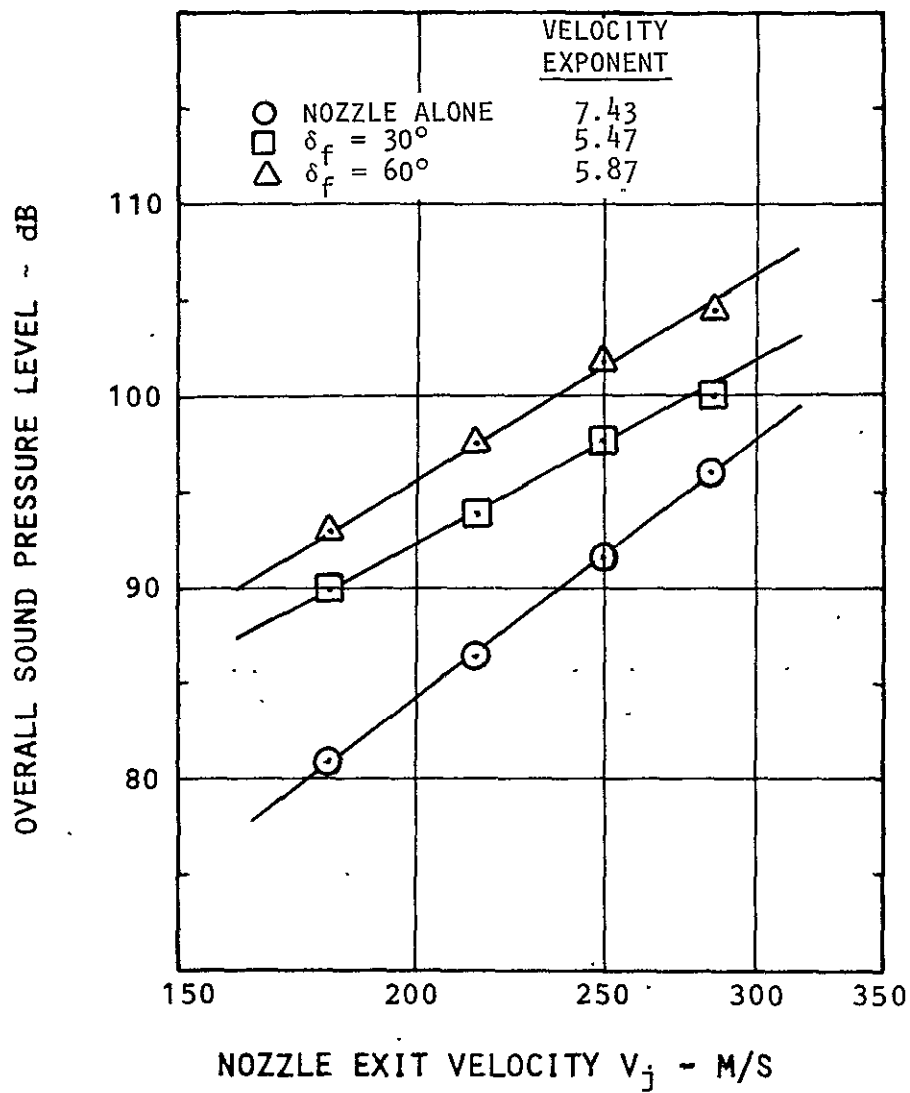
b) $\theta = 120^\circ$

FIGURE 4-41. (CONCLUDED)

LARGE-SCALE MODEL AT 6.1 METERS RADIUS

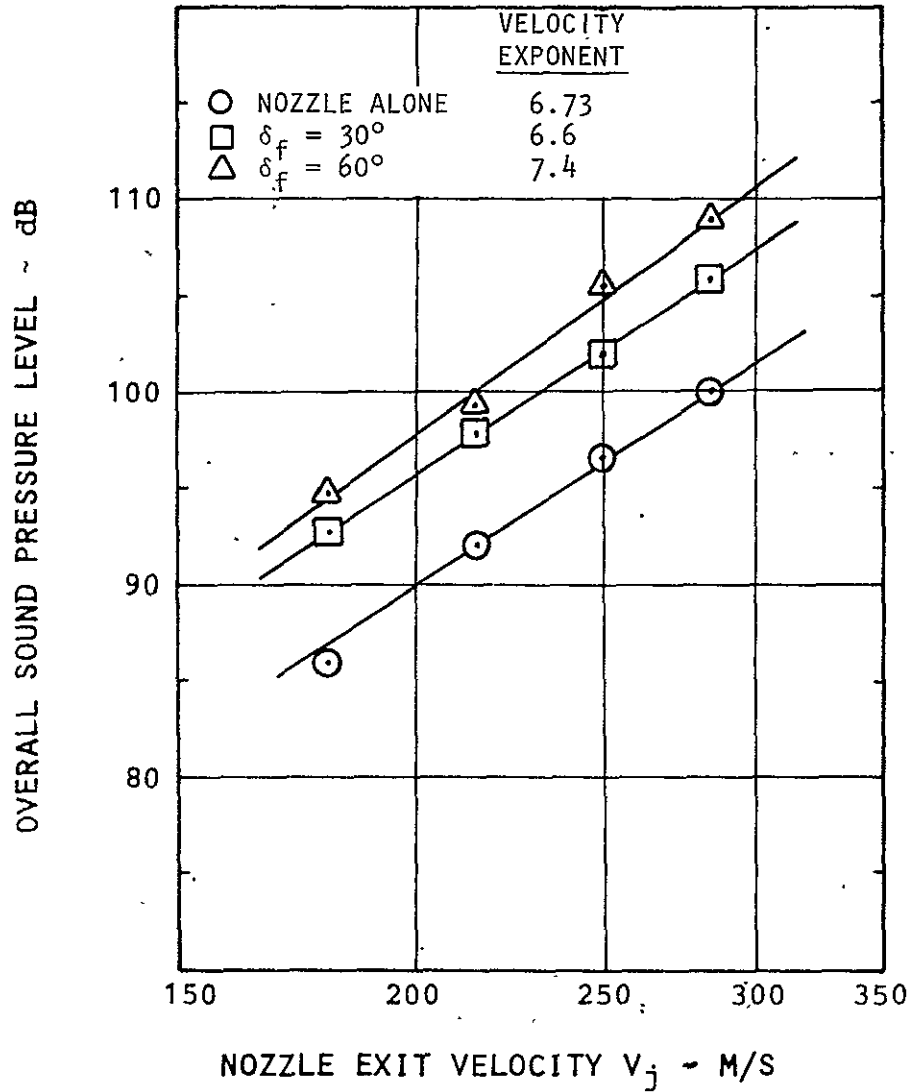
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-42. EFFECT OF FLAP ANGLE ON VELOCITY EXPONENT

LARGE-SCALE MODEL AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-42. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

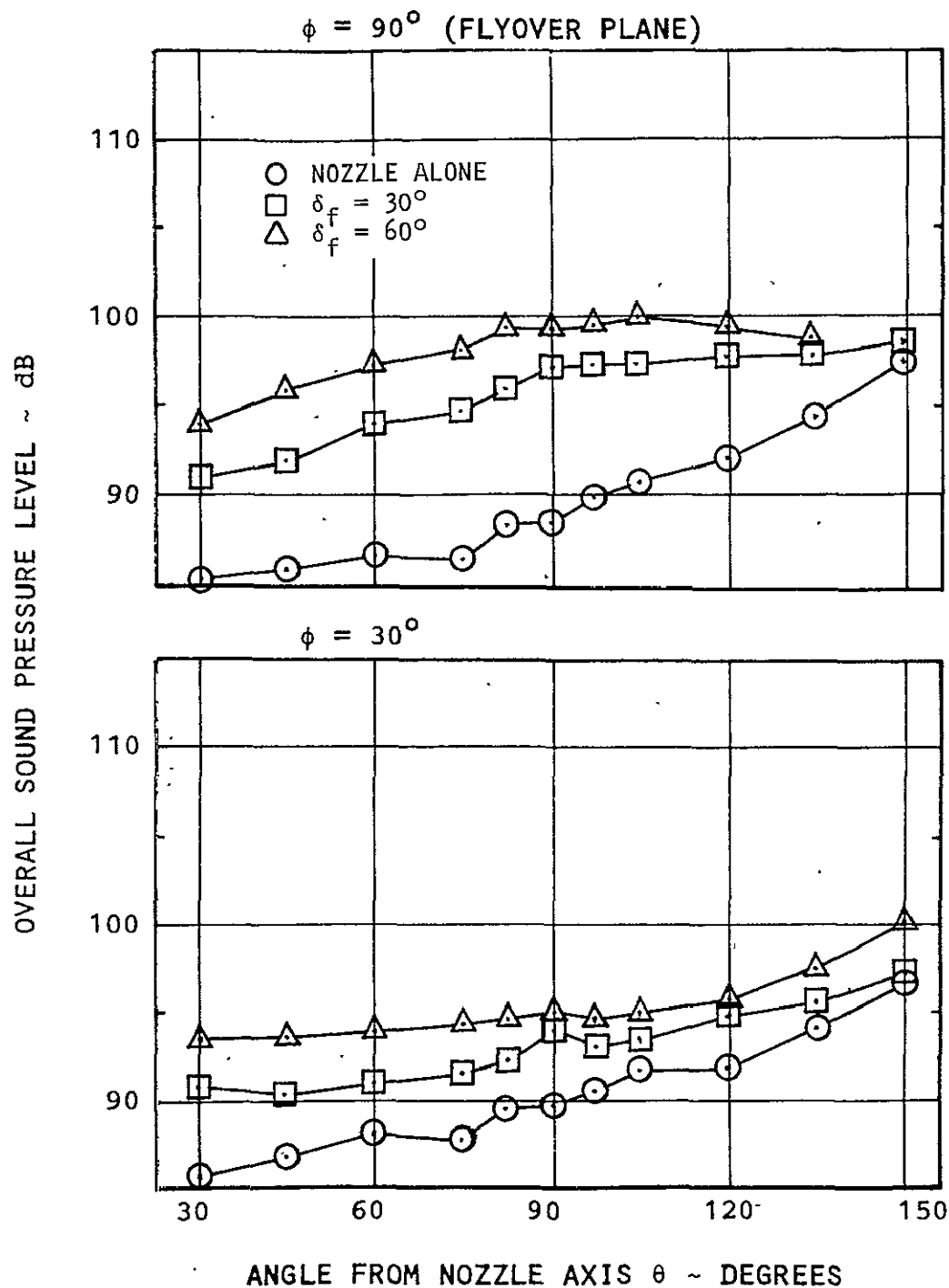


FIGURE 4-43. EFFECT OF FLAP ANGLE ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

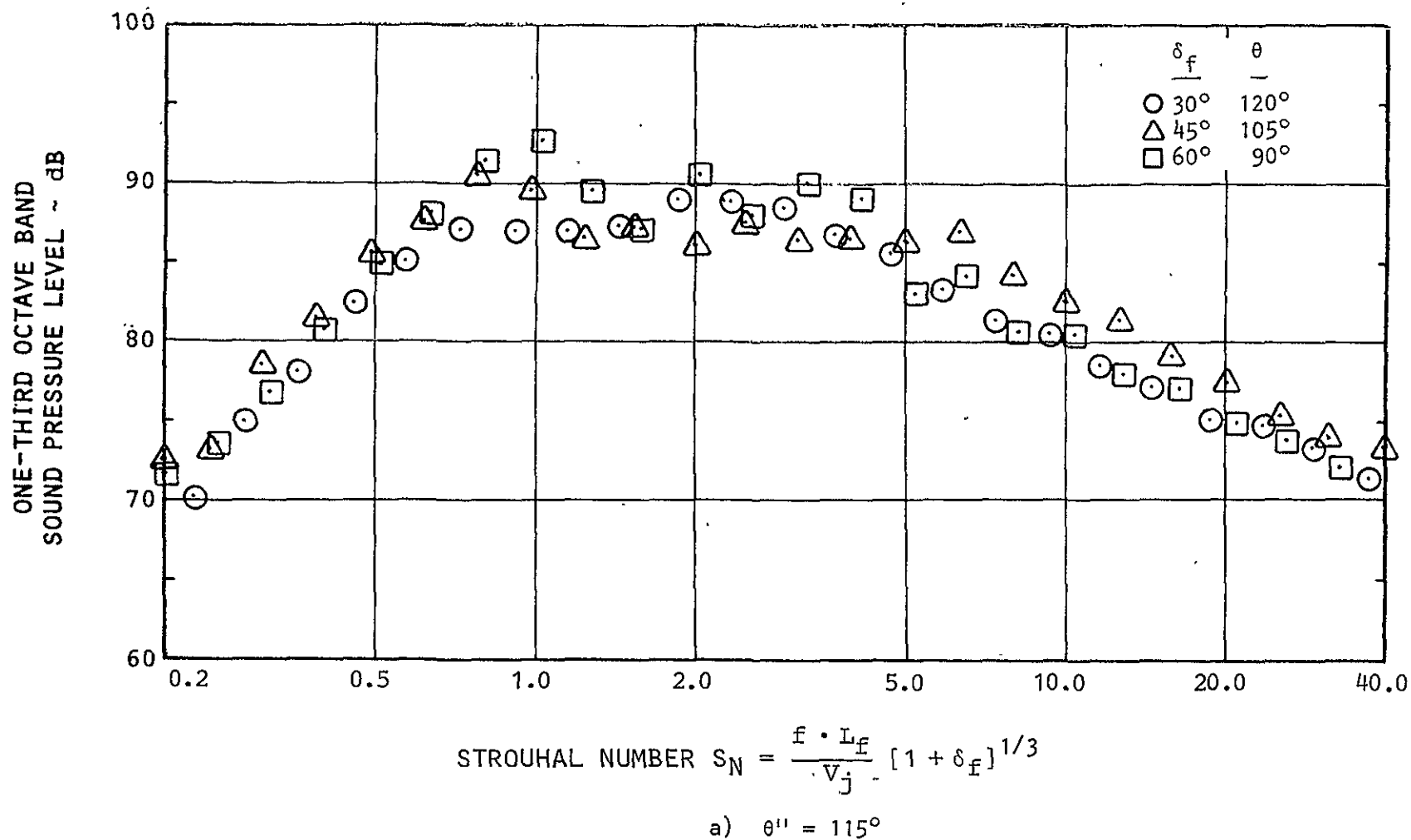


FIGURE 4-44. EFFECT OF FLAP ANGLE ON NON-DIMENSIONALIZED SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

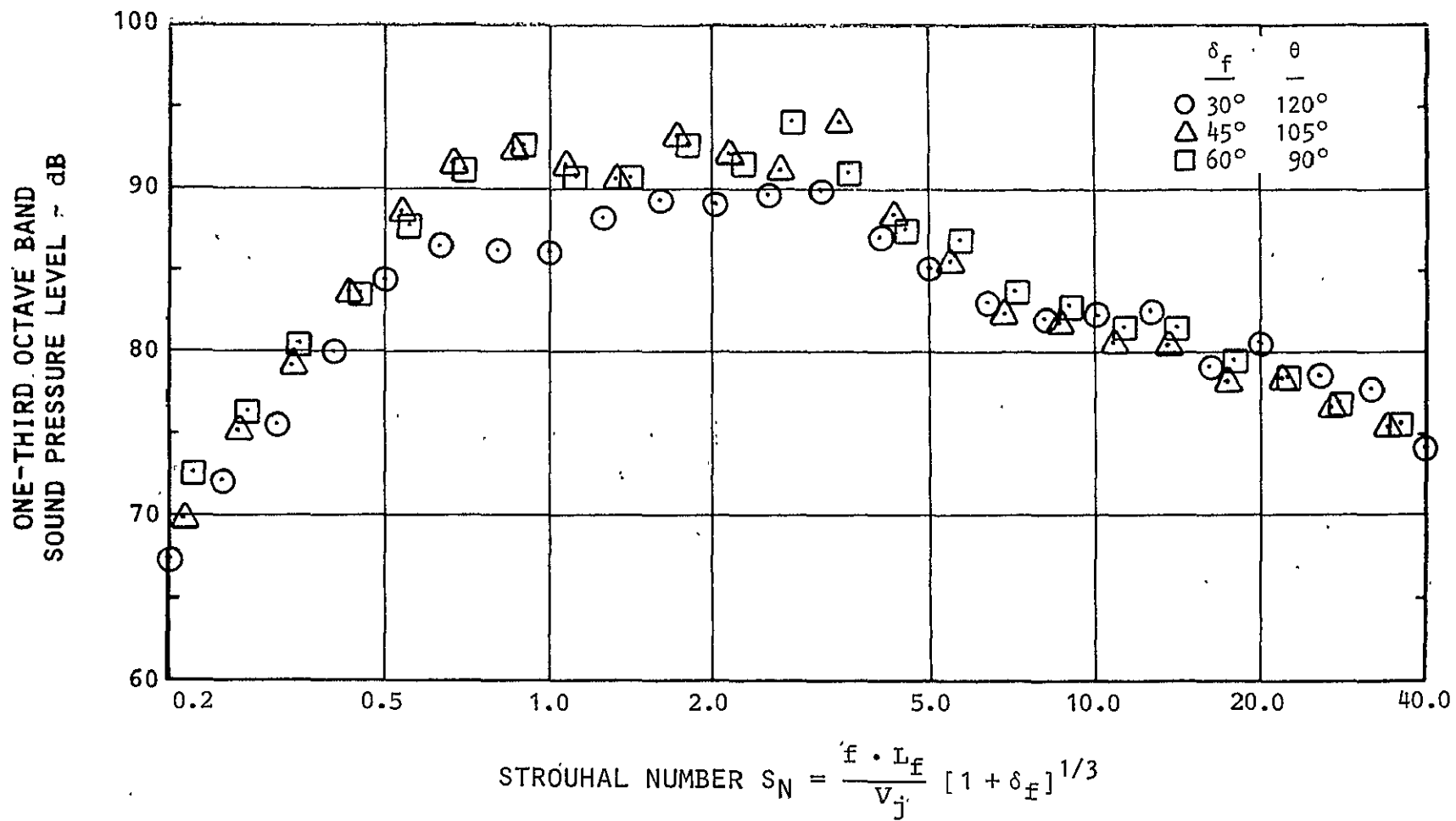
b) $\theta'' = 130^\circ$

FIGURE 4-44. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

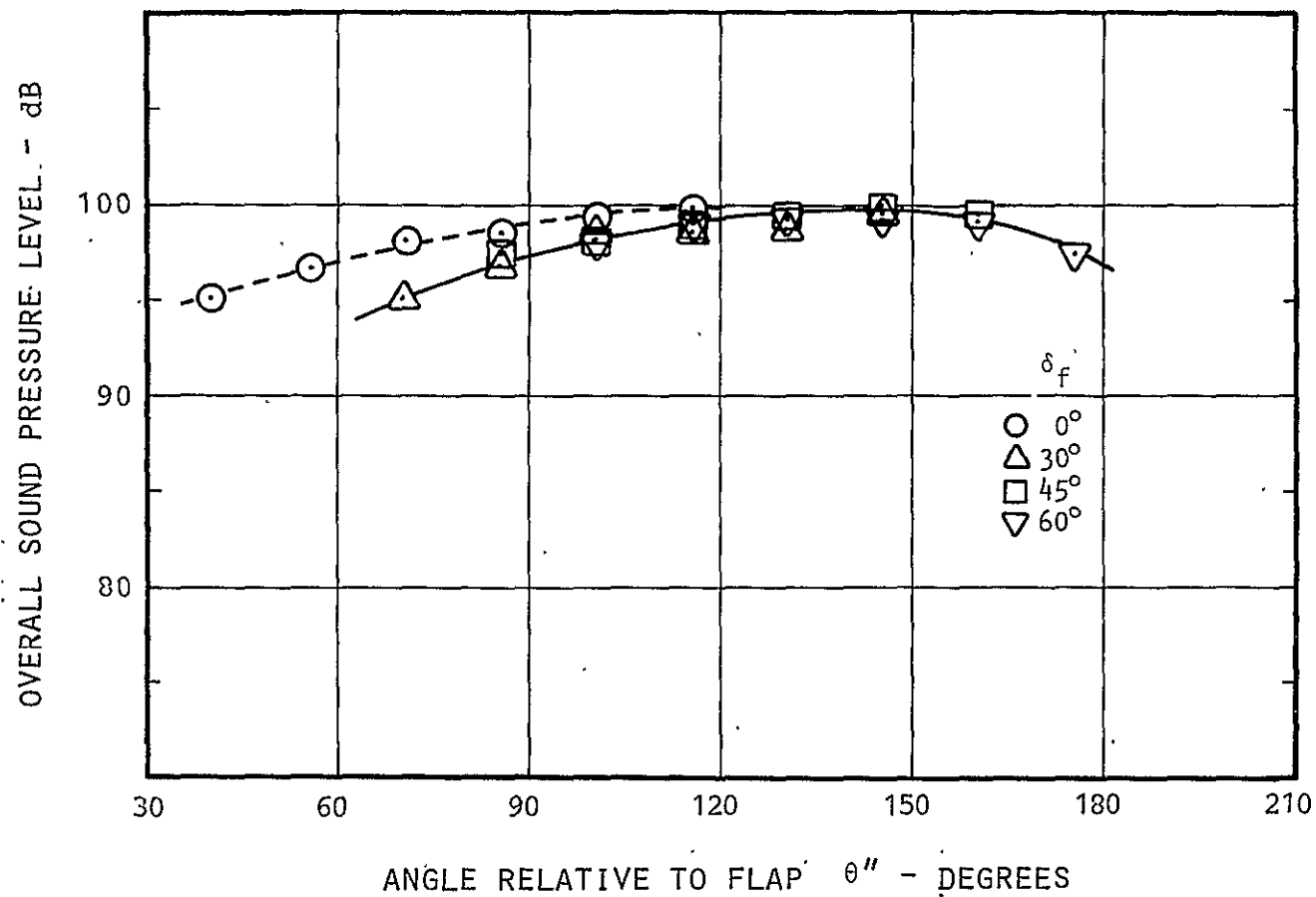
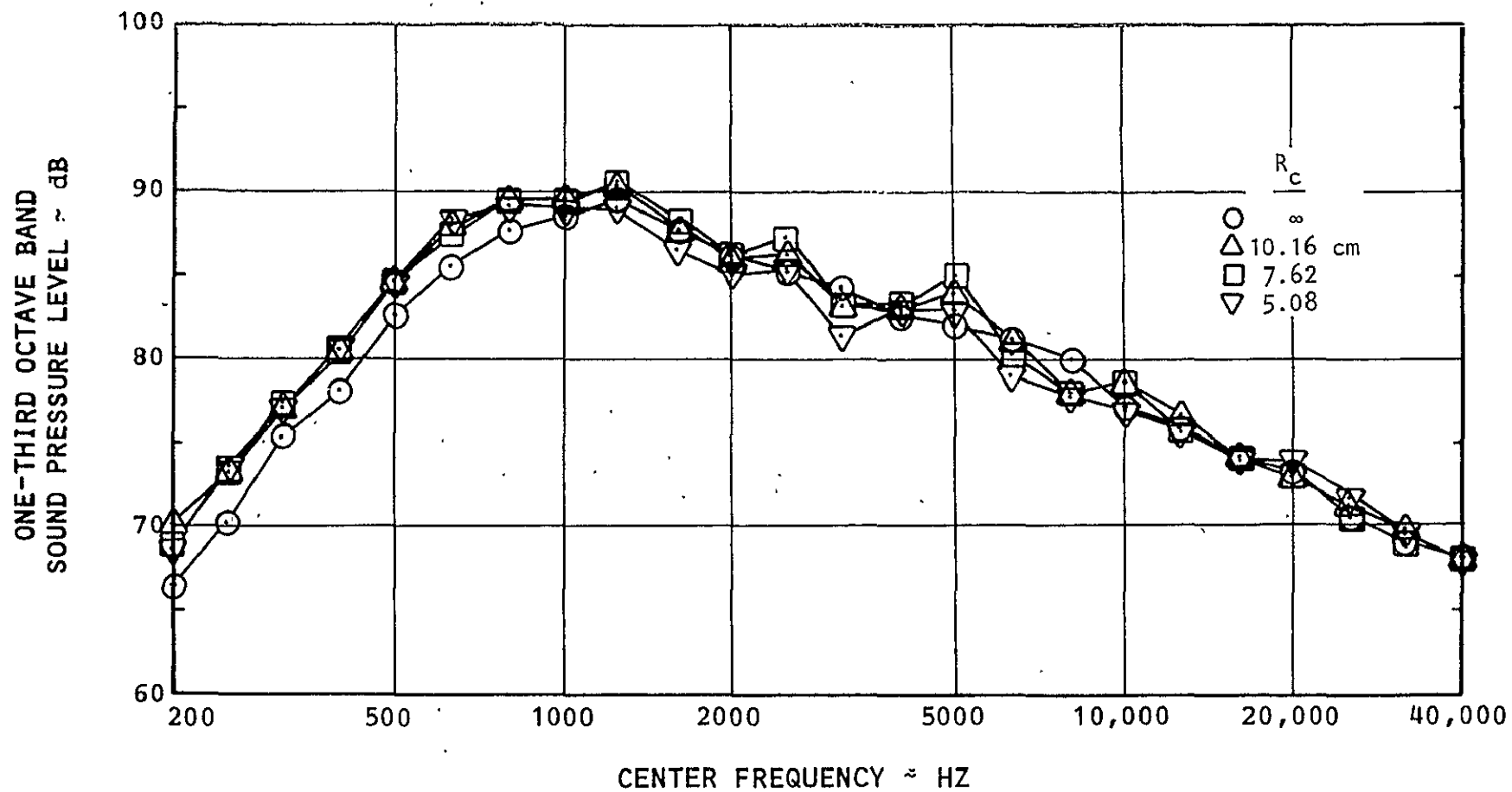


FIGURE 4-45. DIRECTIVITY RELATIVE TO FLAP DIRECTION

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-46. EFFECT OF FLAP KNEE RADIUS ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

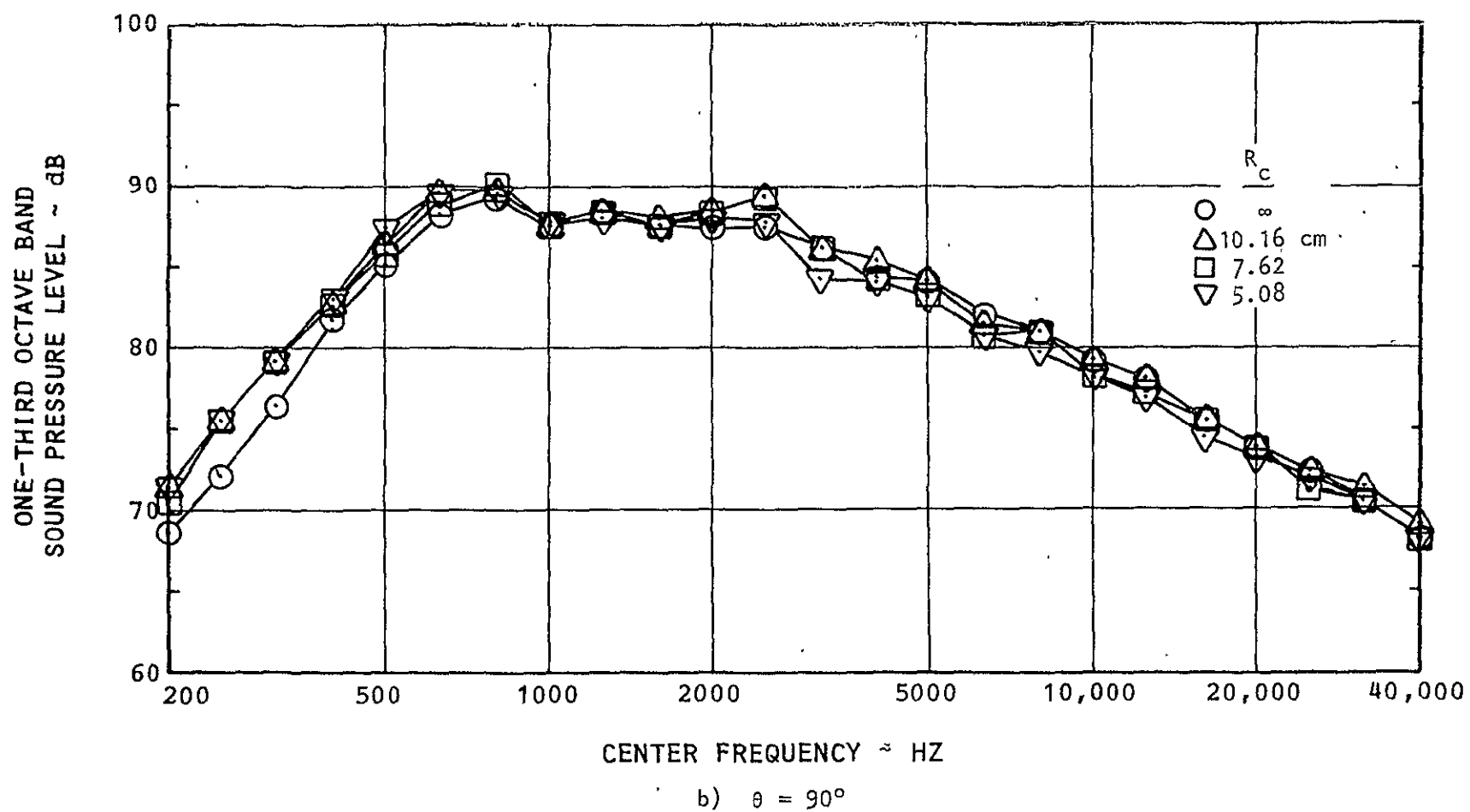


FIGURE 4-46. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

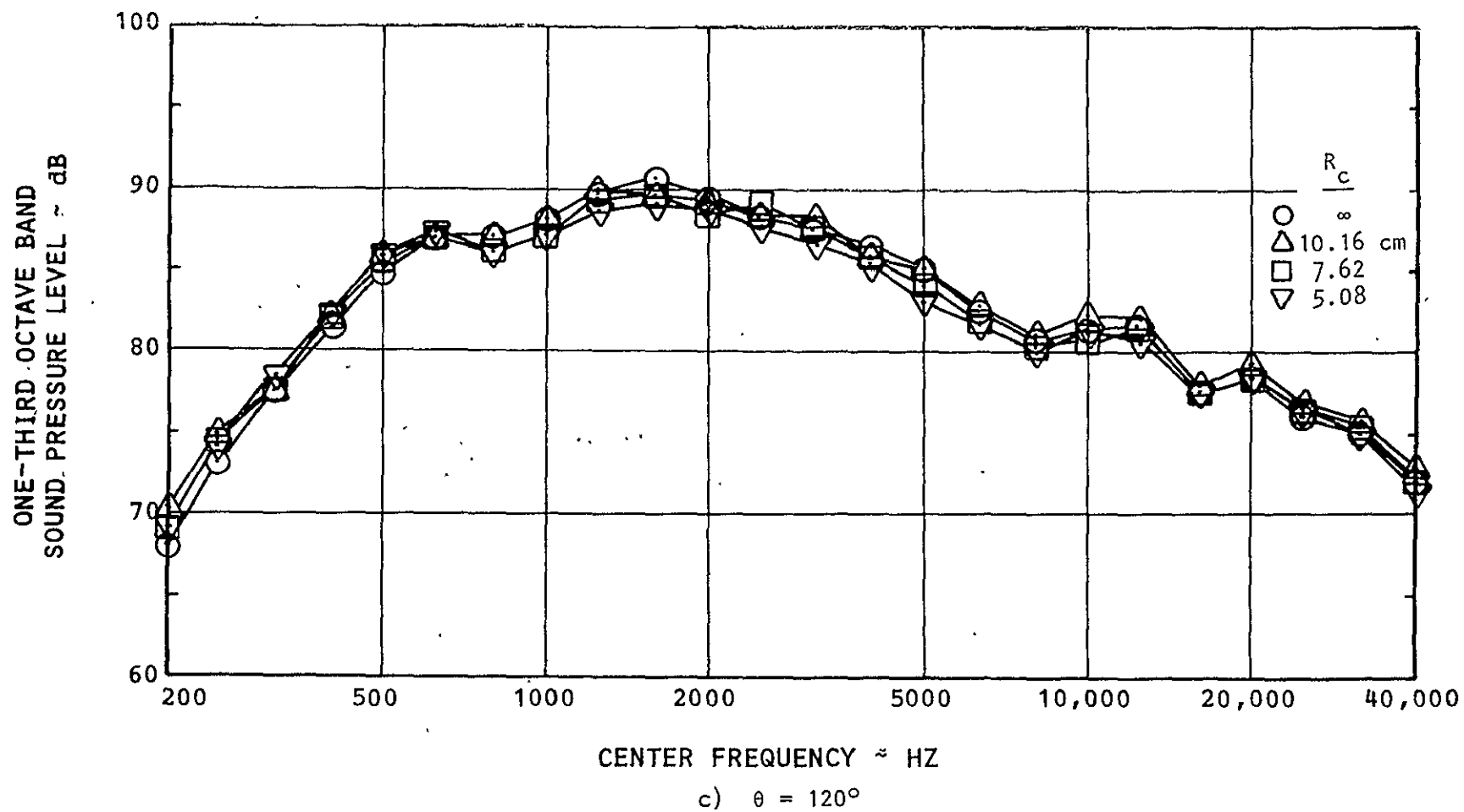
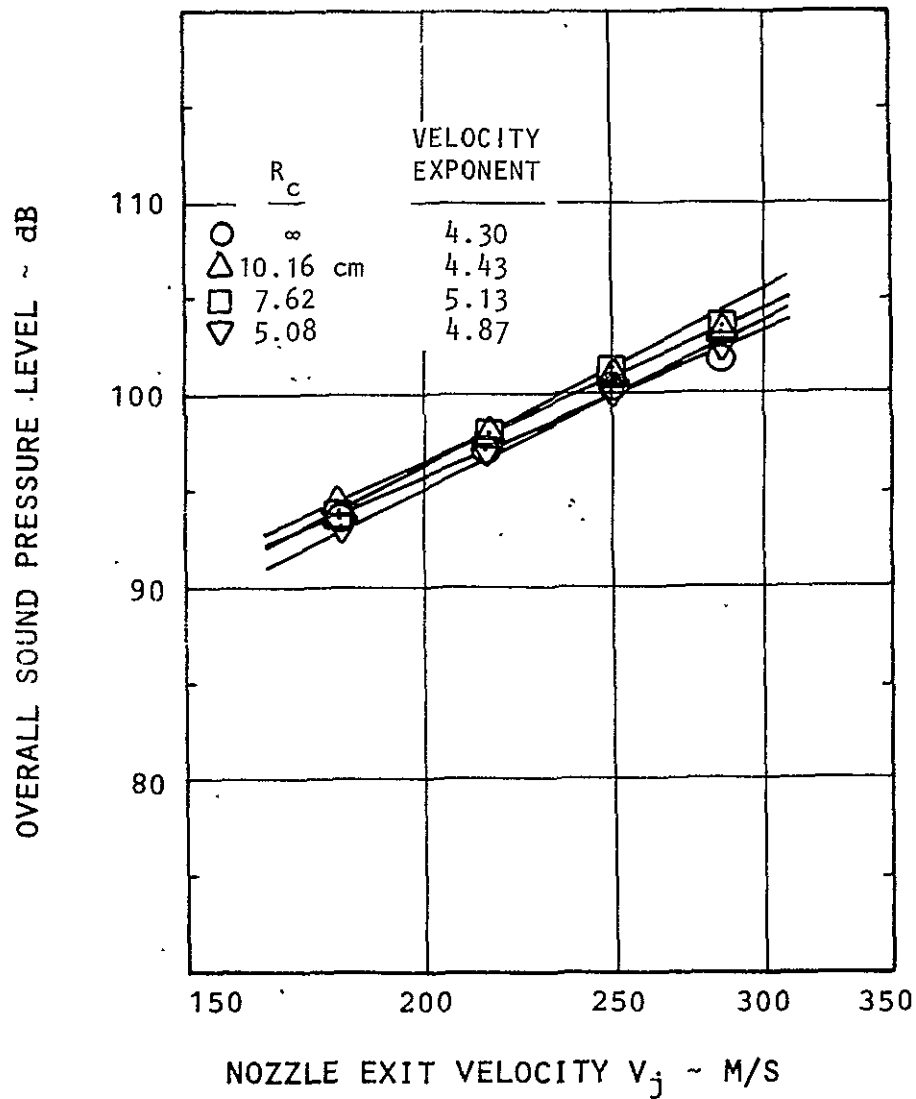


FIGURE 4-46. (CONCLUDED)

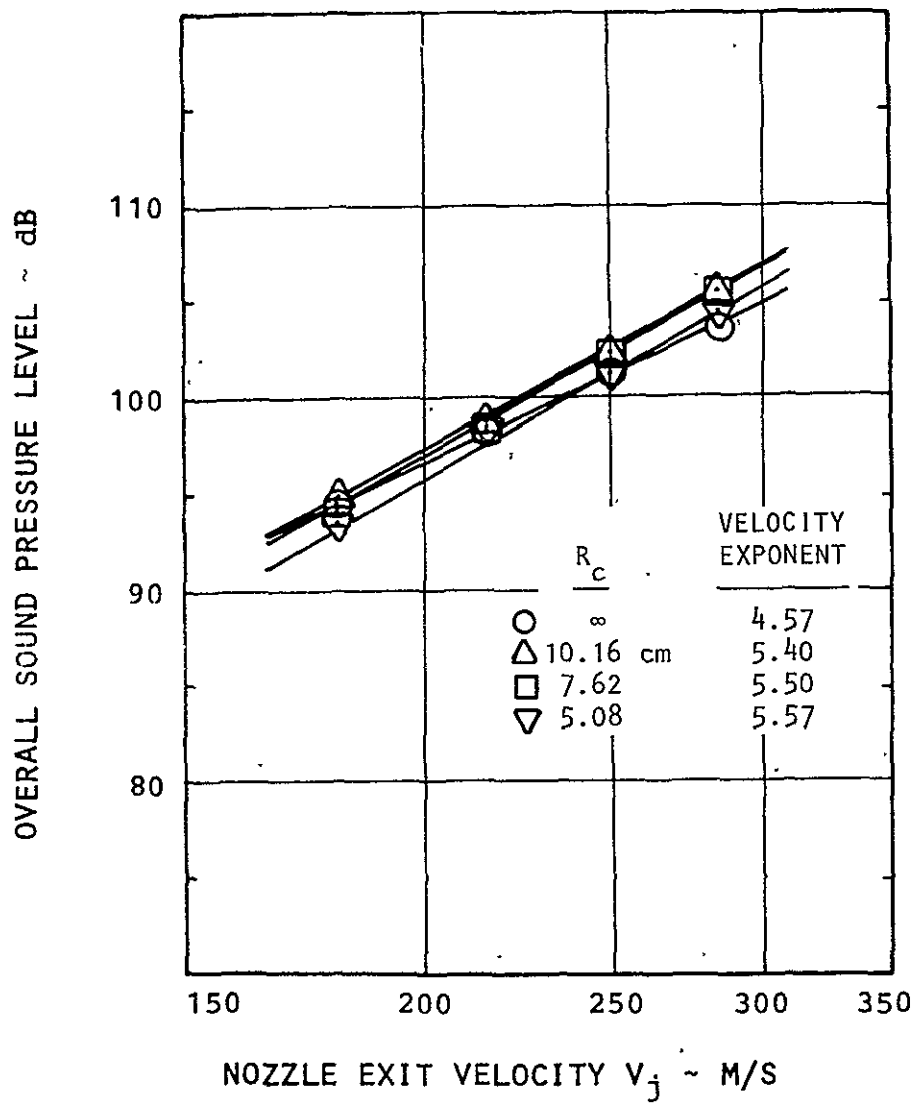
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS.
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-47. EFFECT OF FLAP KNEE RADIUS ON VELOCITY EXPONENT

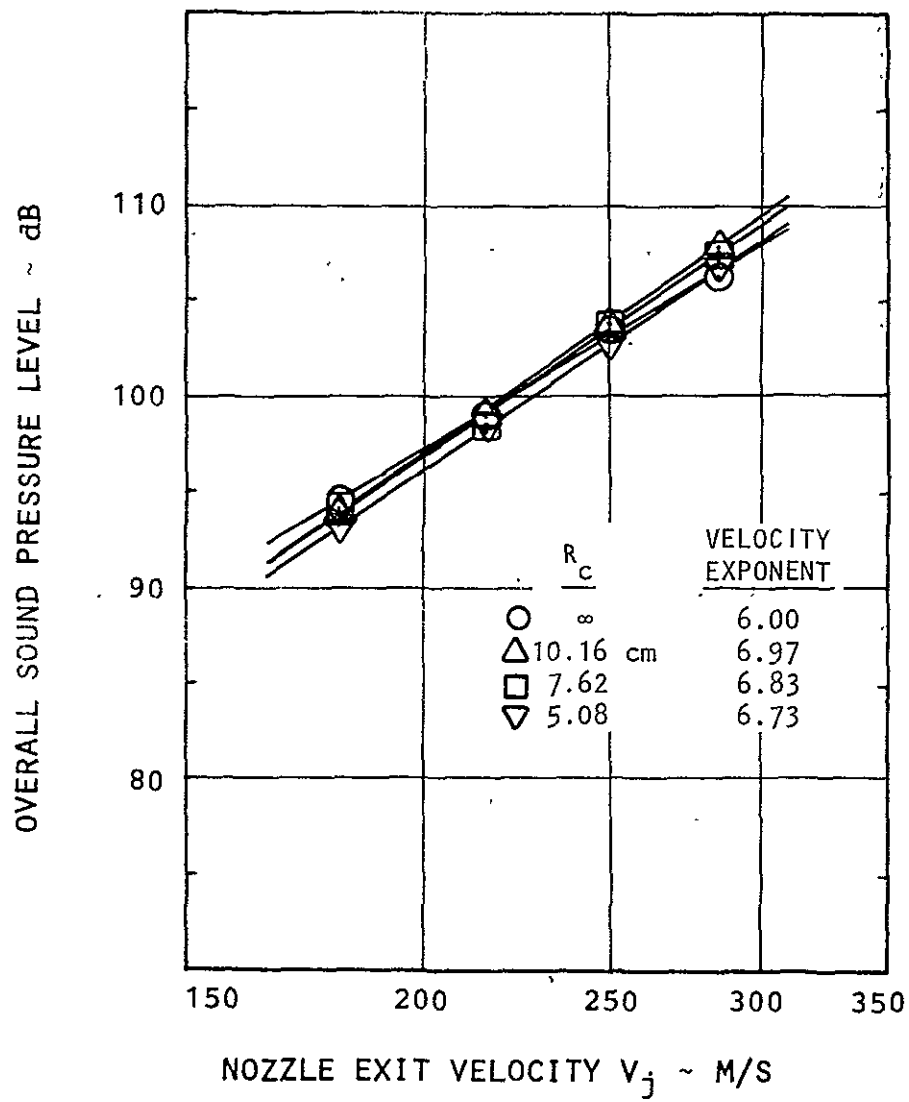
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-47. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-47. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

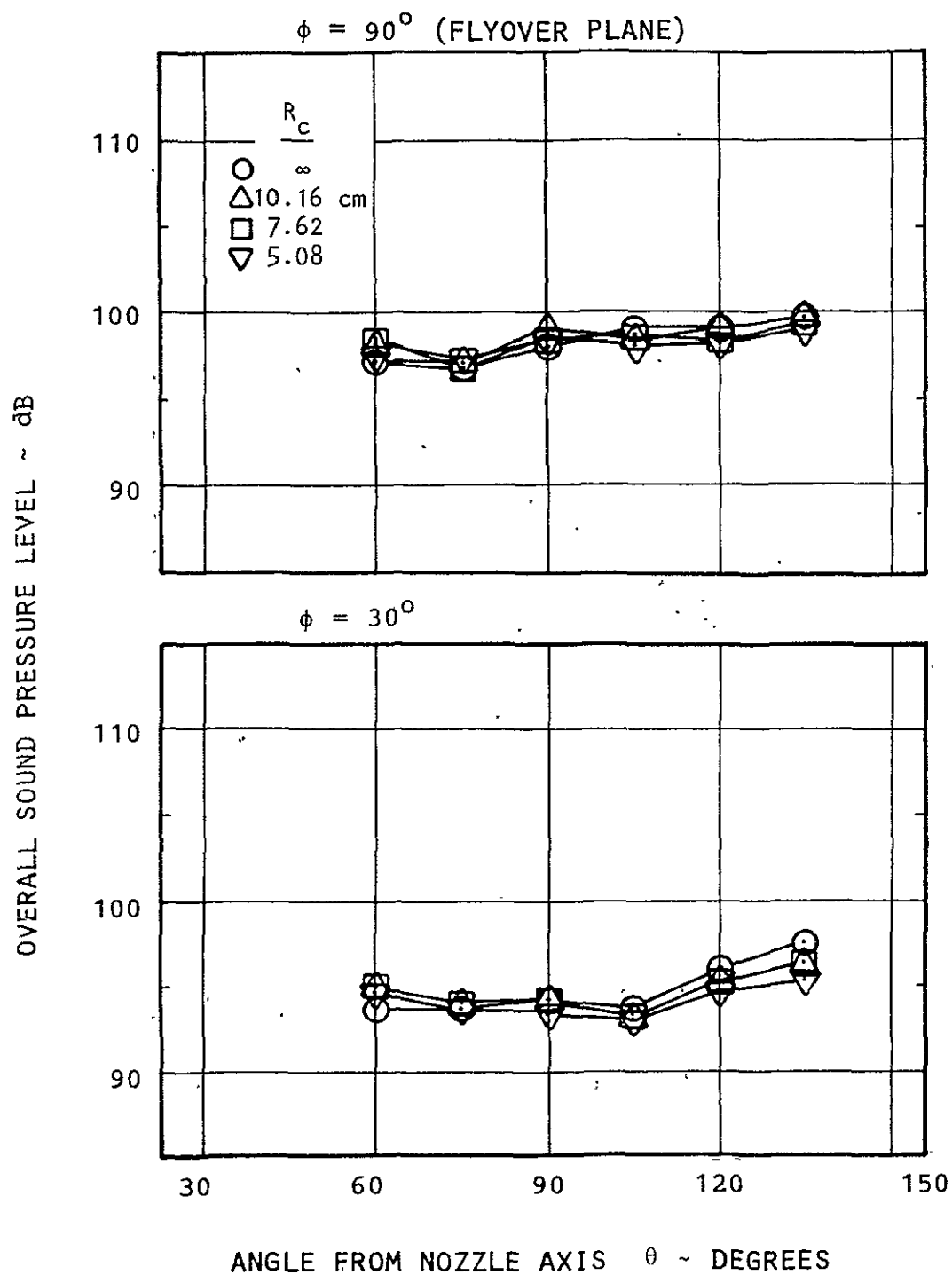
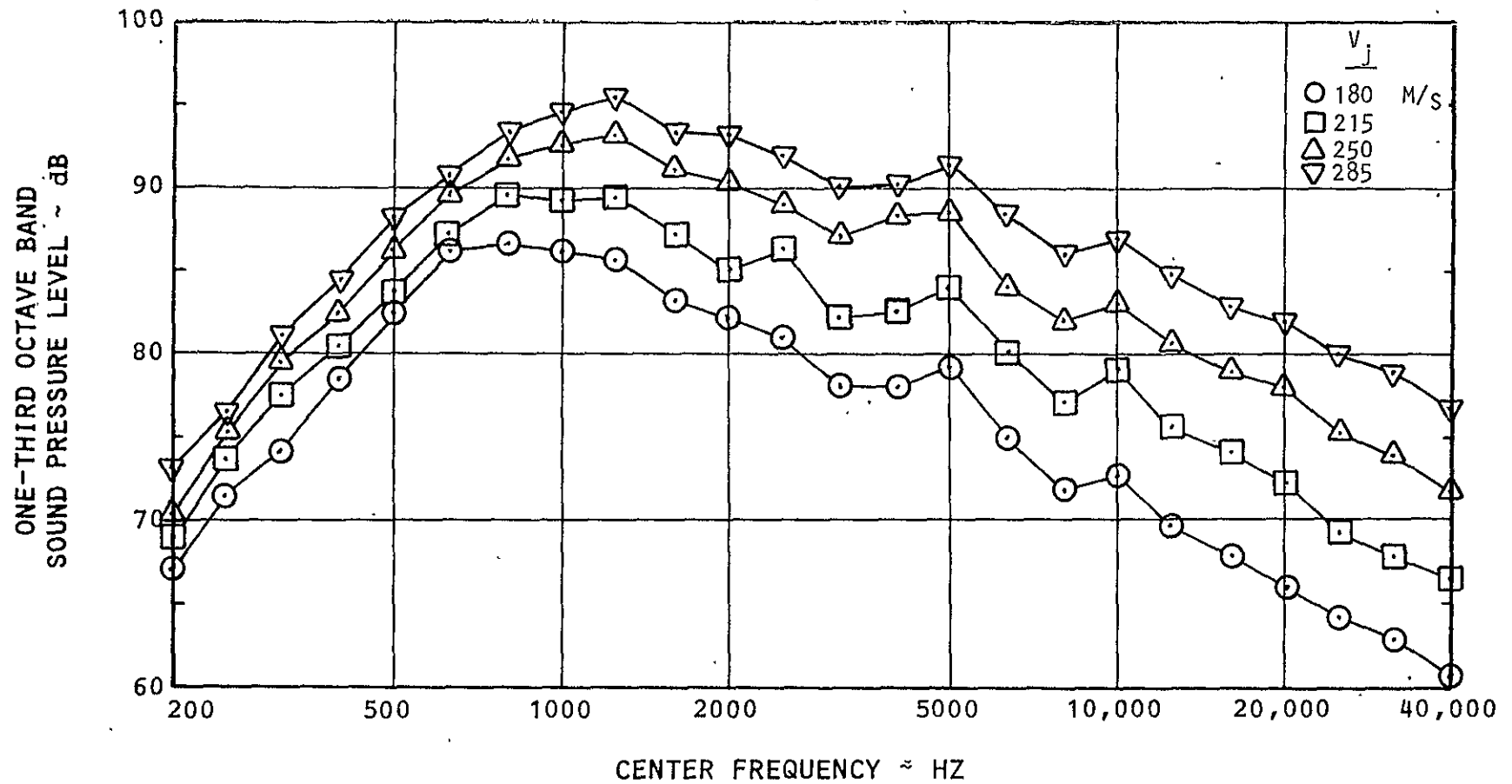


FIGURE 4-48. EFFECT OF FLAP KNEE RADIUS ON DIRECTIVITY

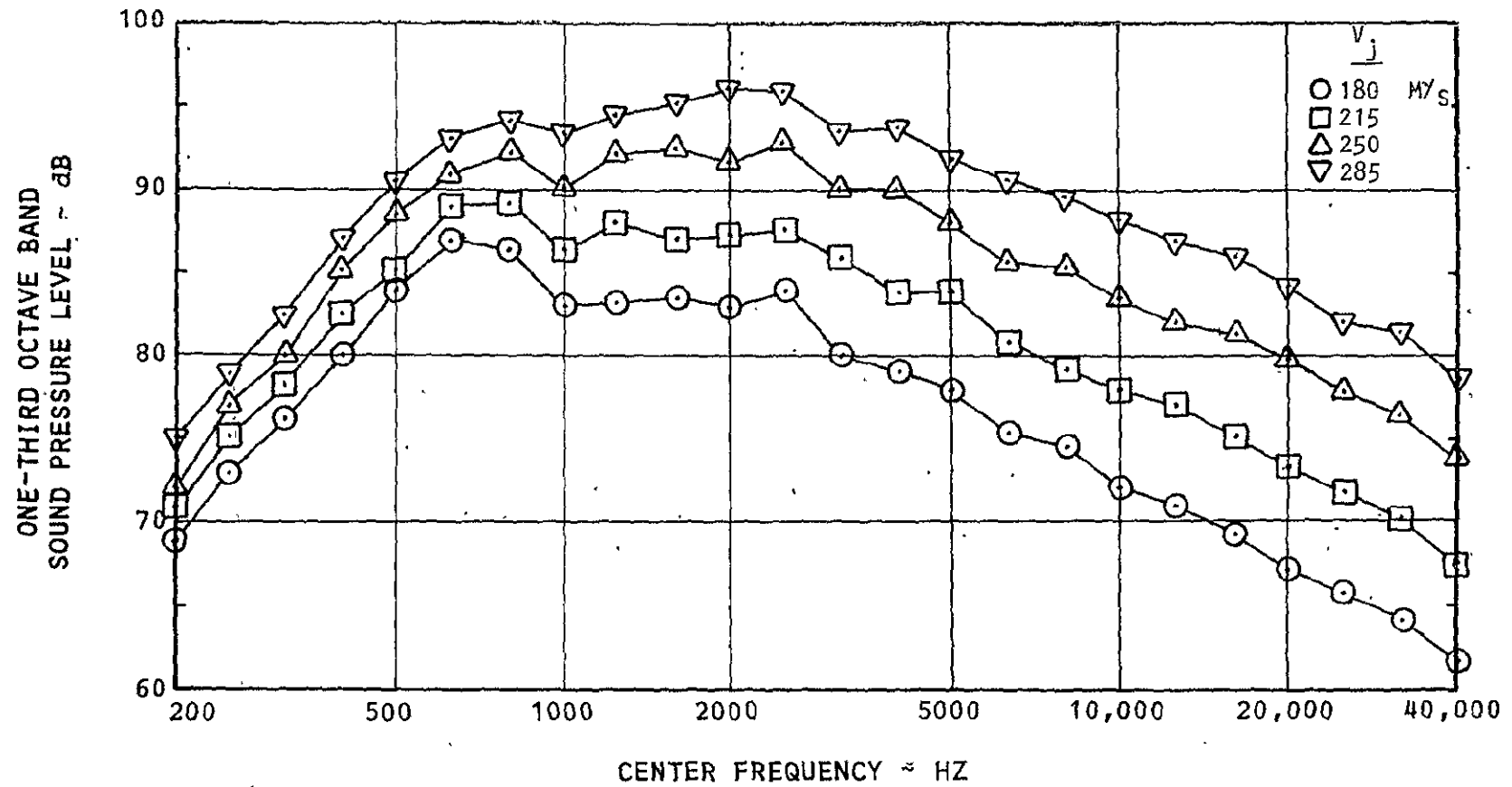
SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-49. EFFECT OF JET VELOCITY ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-49. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

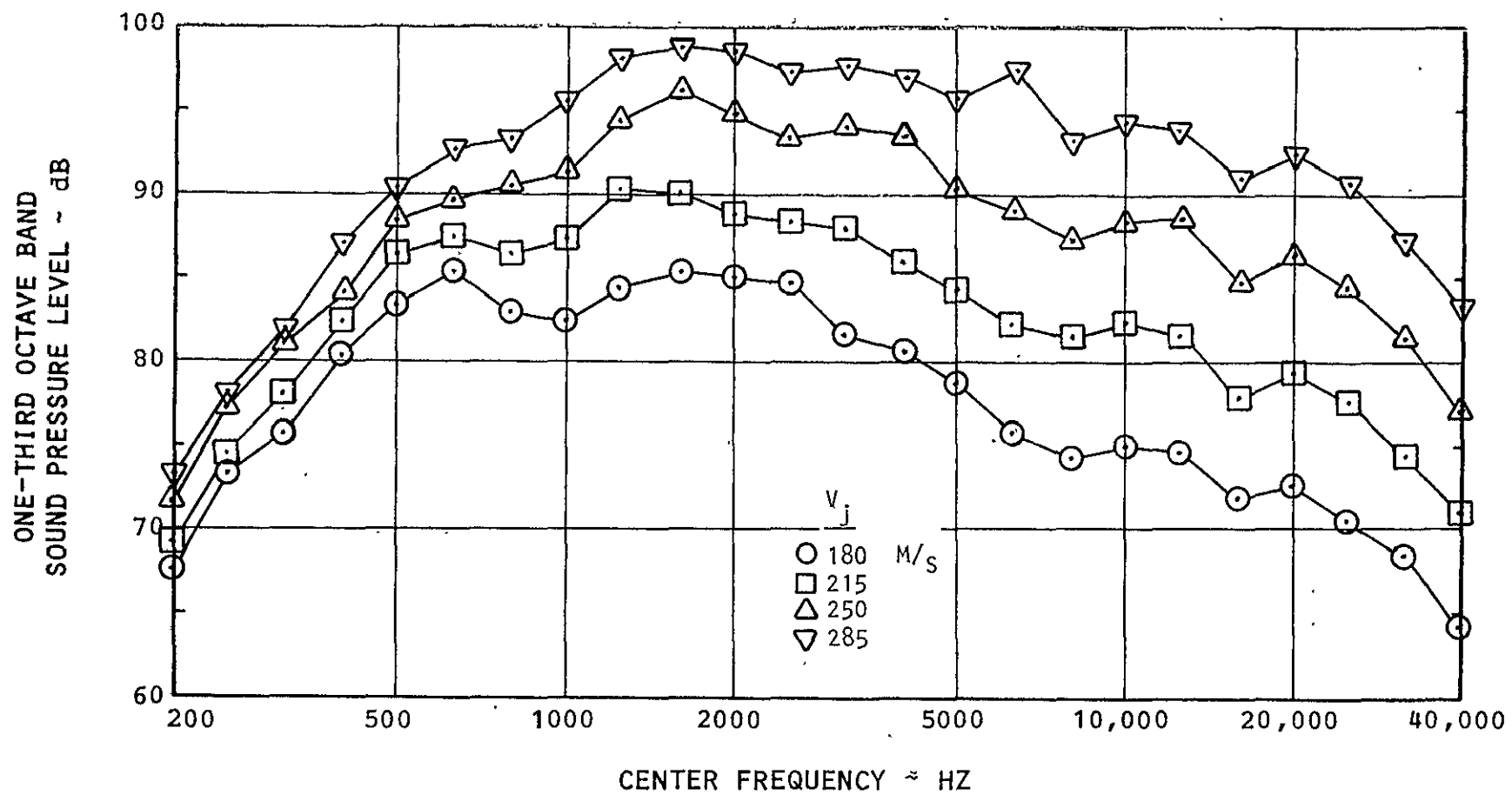
c) $\theta = 120^\circ$

FIGURE 4-49. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

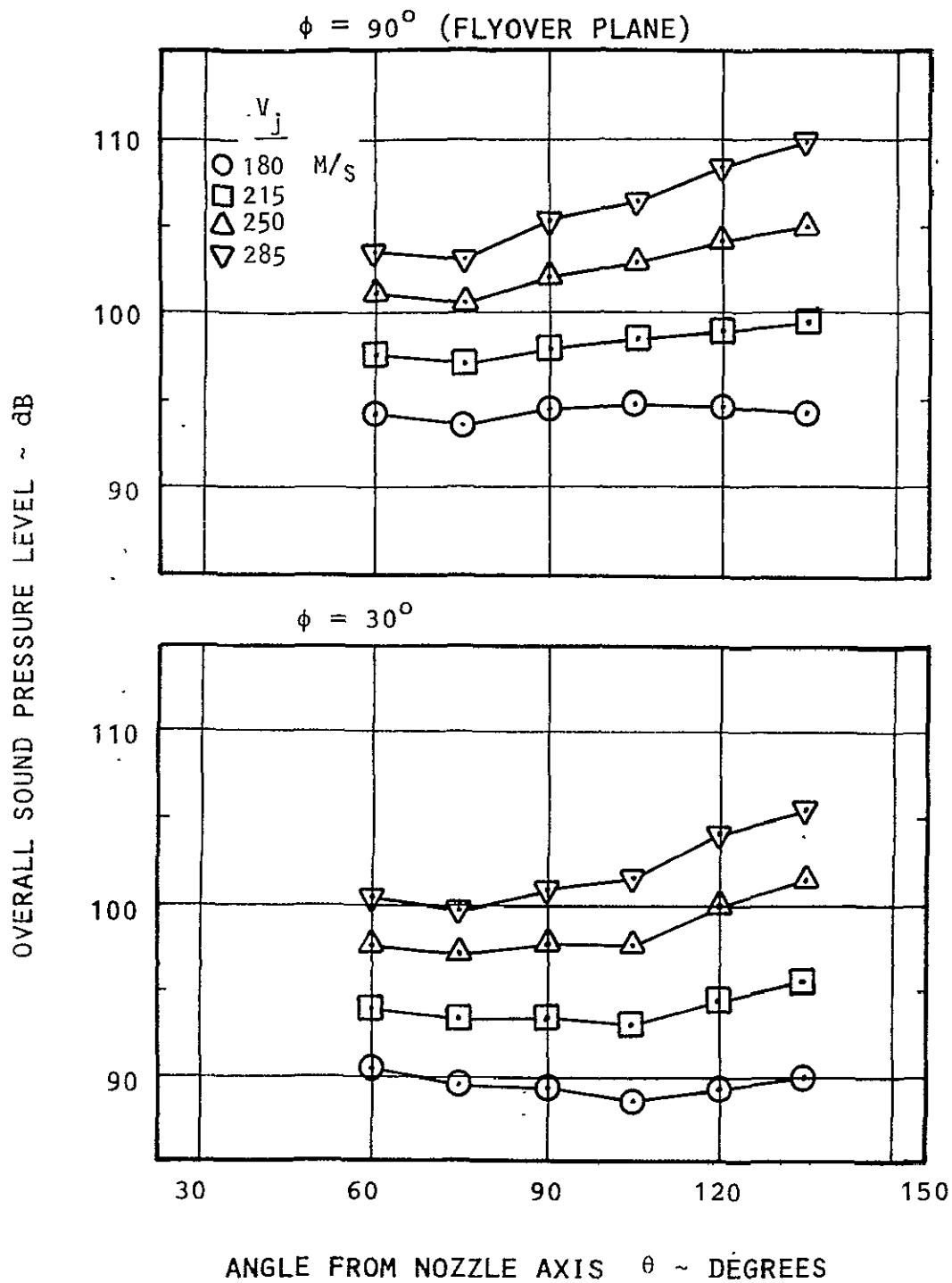


FIGURE 4-50. EFFECT OF JET VELOCITY ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

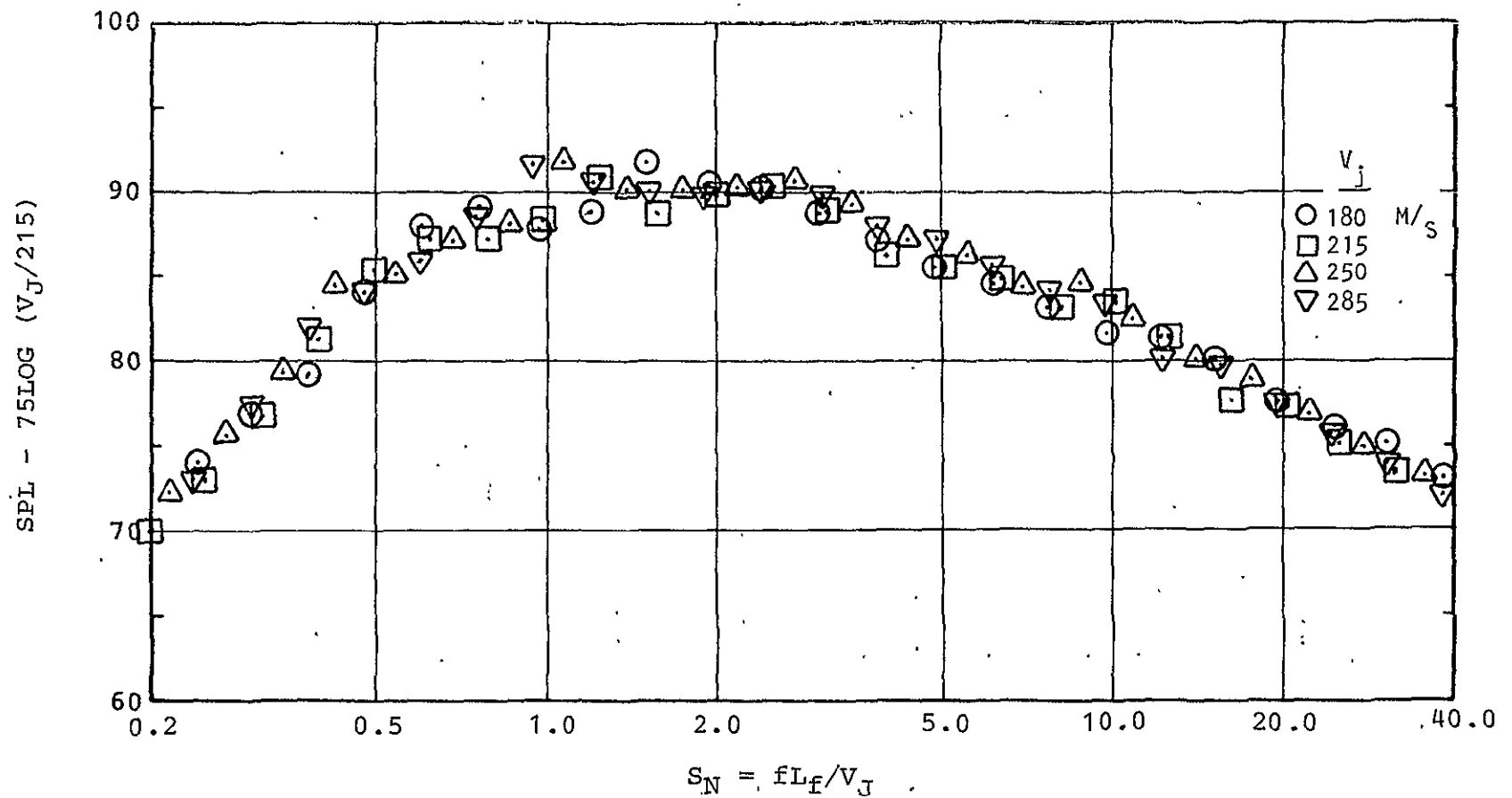


FIGURE 4-51. EFFECT OF JET VELOCITY ON NON-DIMENSIONALIZED SPECTRUM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

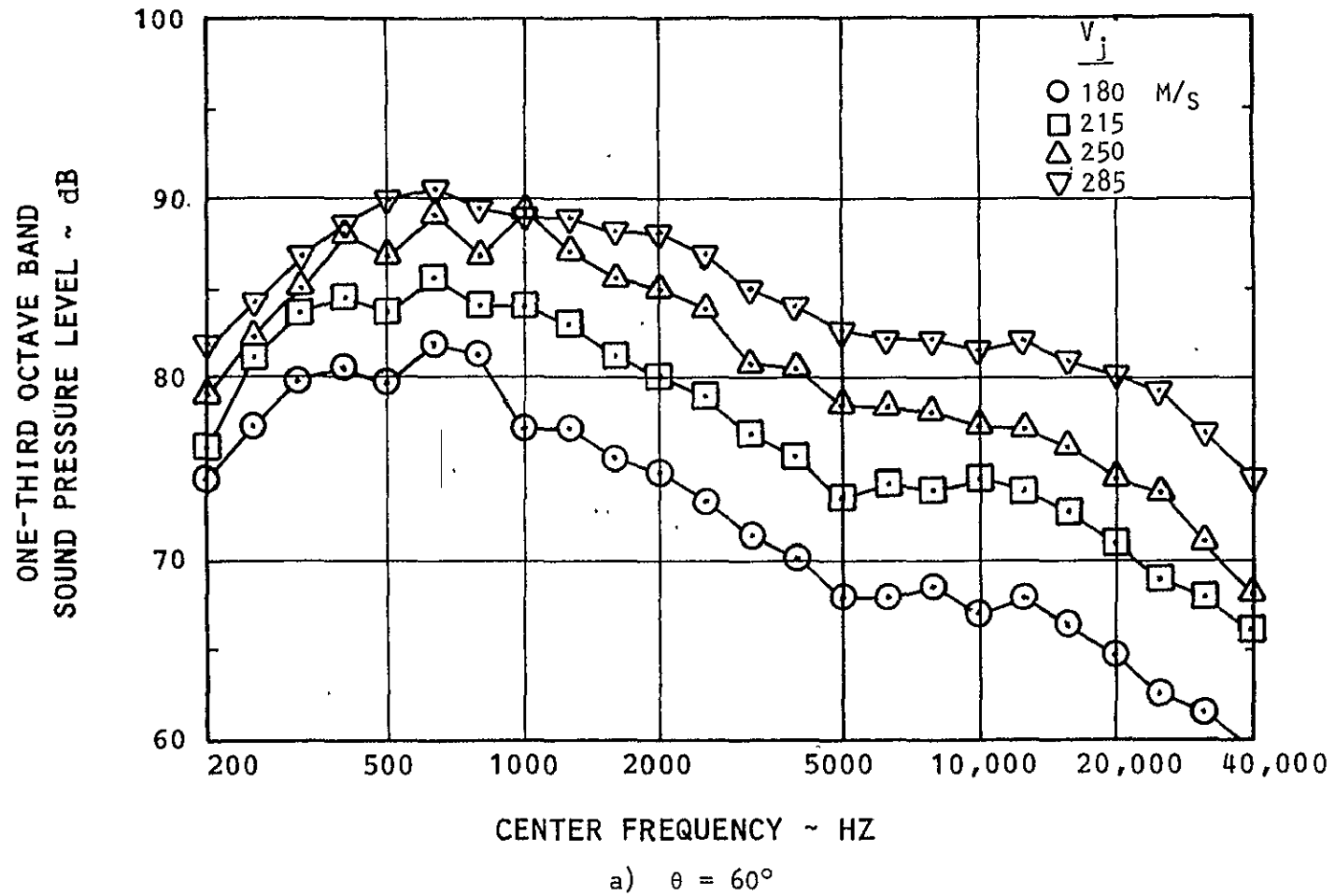


FIGURE 4-52. EFFECT OF JET VELOCITY ON SPECTRUM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

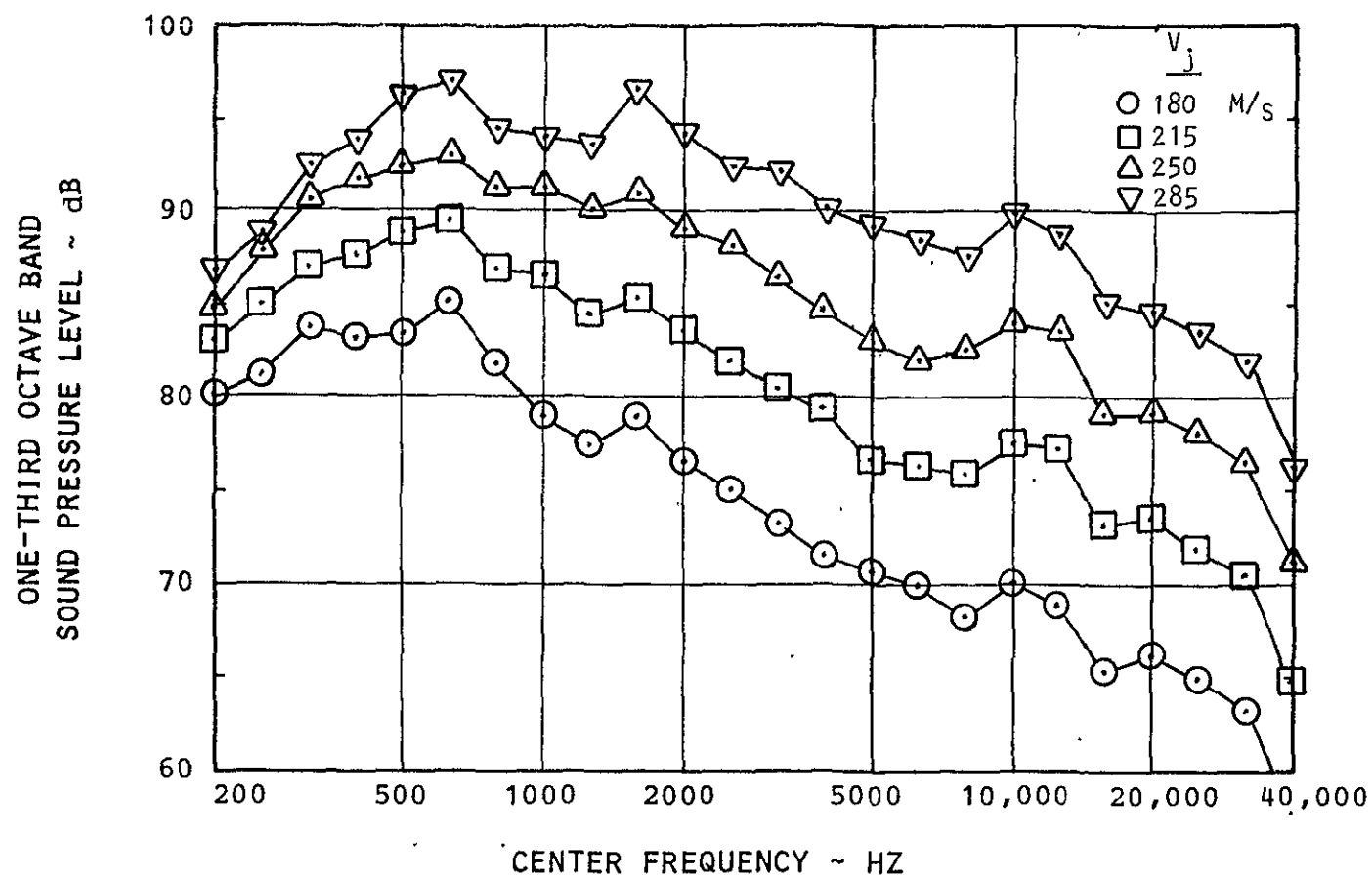
b) $\theta = 120^\circ$

FIGURE 4-52. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

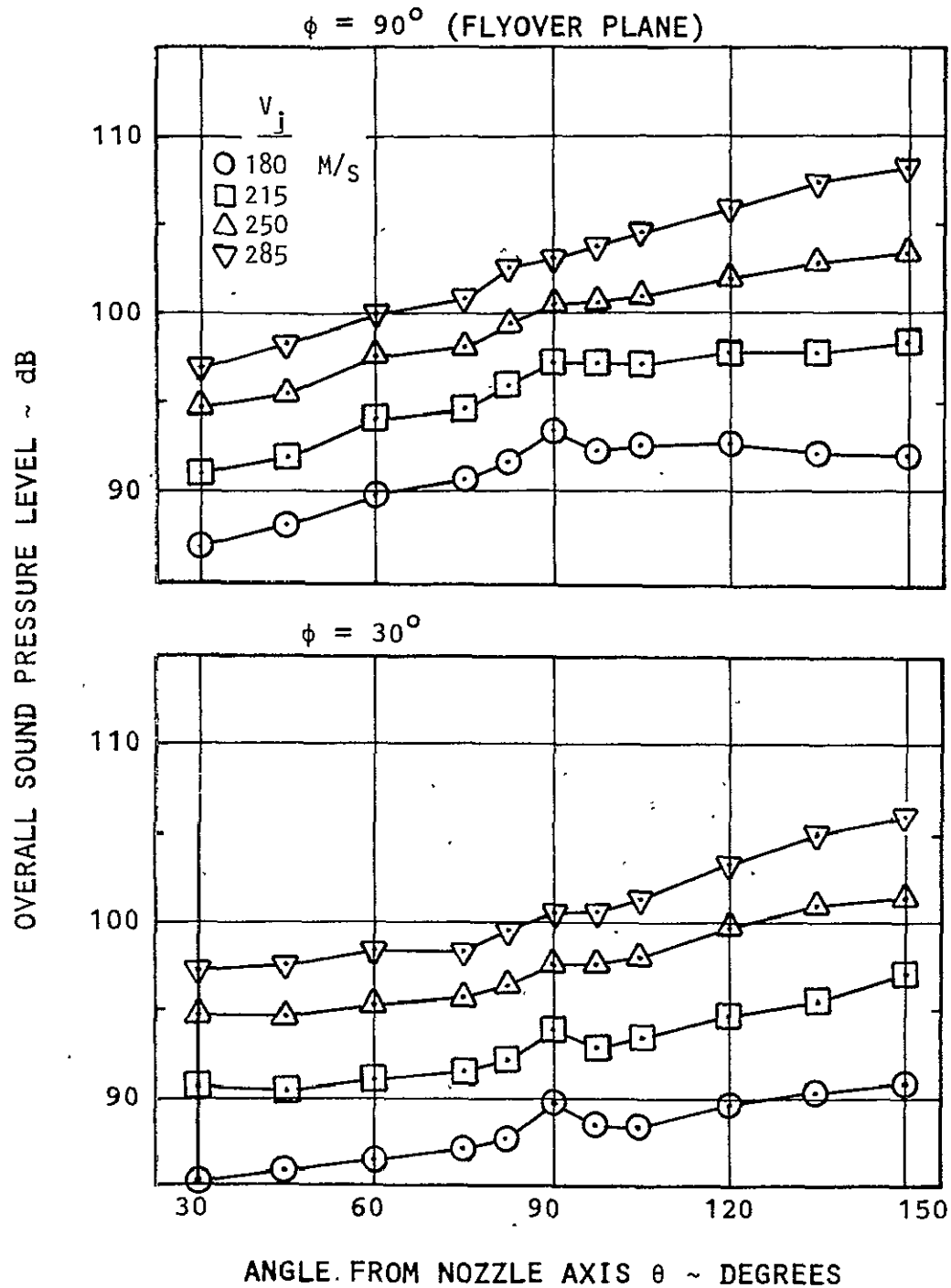


FIGURE 4-53. EFFECT OF JET VELOCITY ON DIRECTIVITY

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

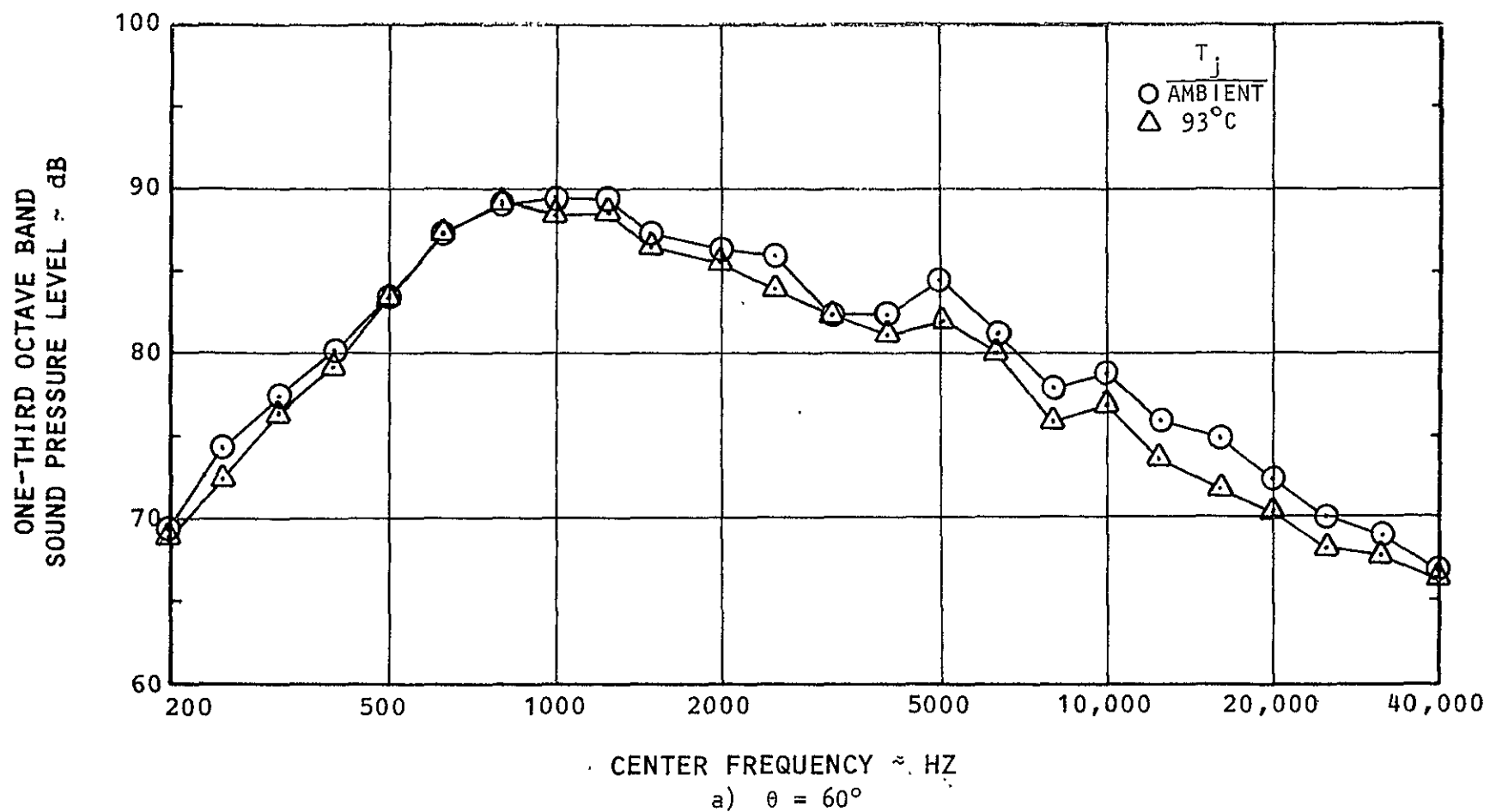


FIGURE 4-54. EFFECT OF JET TEMPERATURE ON SPECTRUM

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

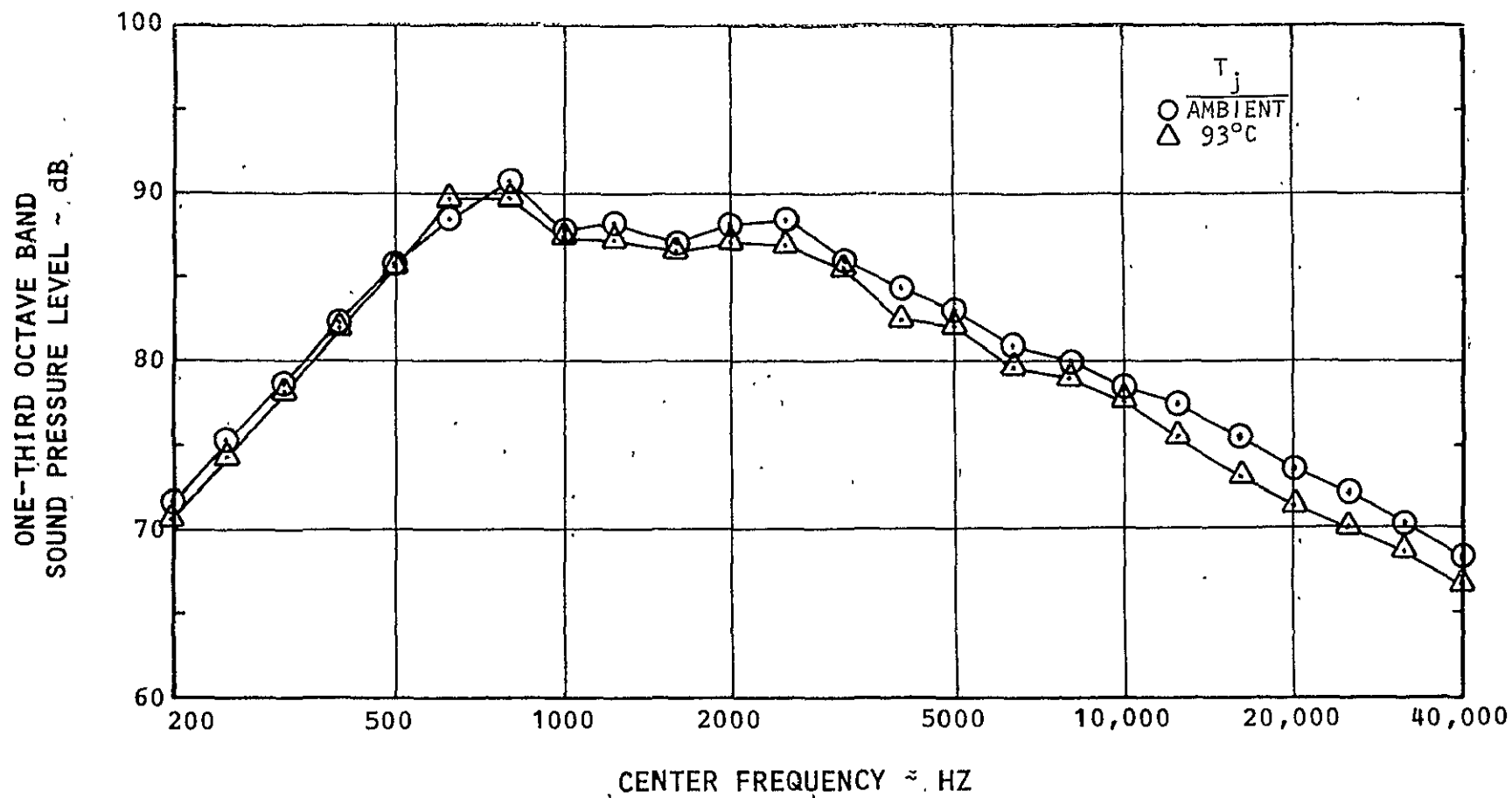
b) $\theta = 90^\circ$

FIGURE 4-54. (CONTINUED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

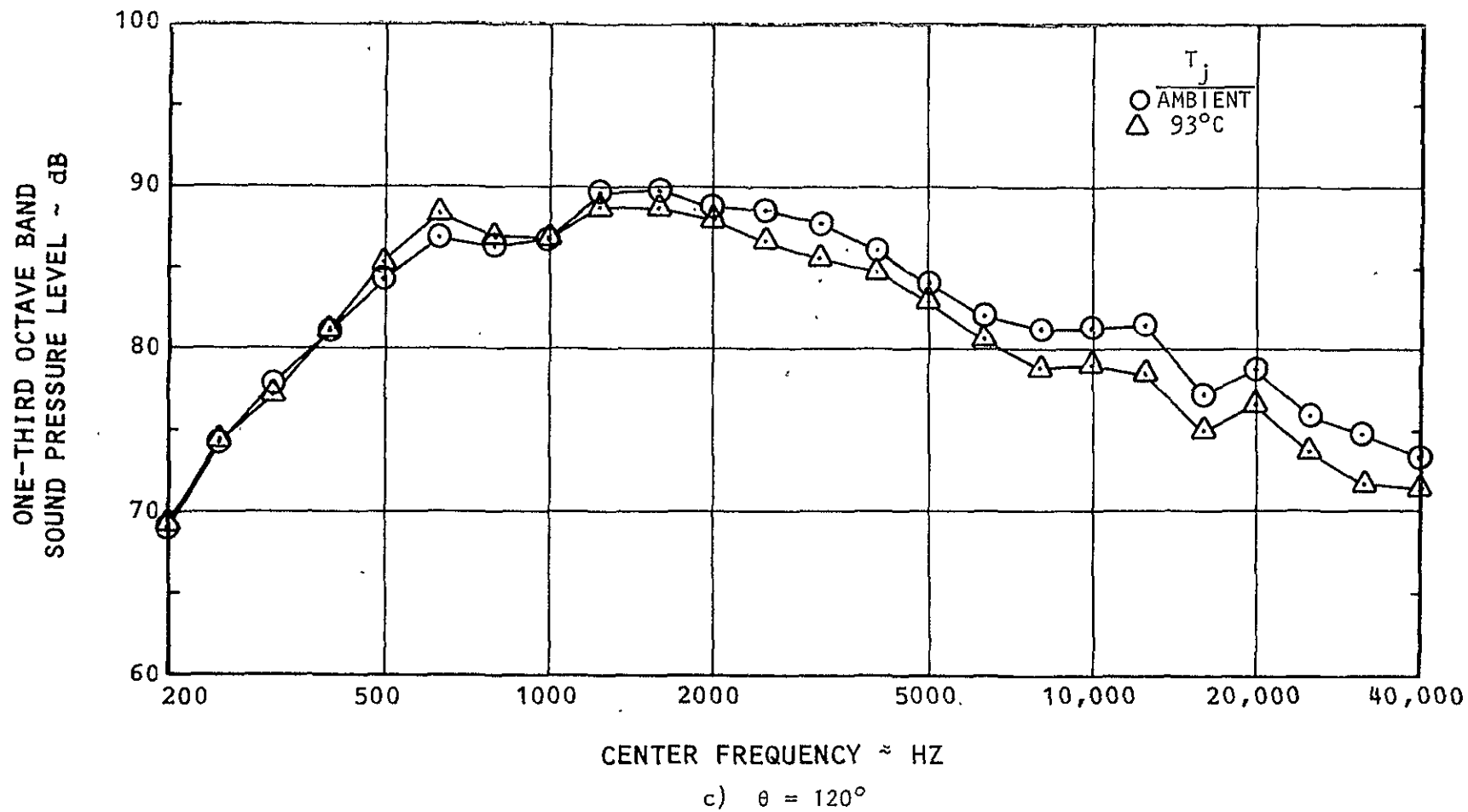
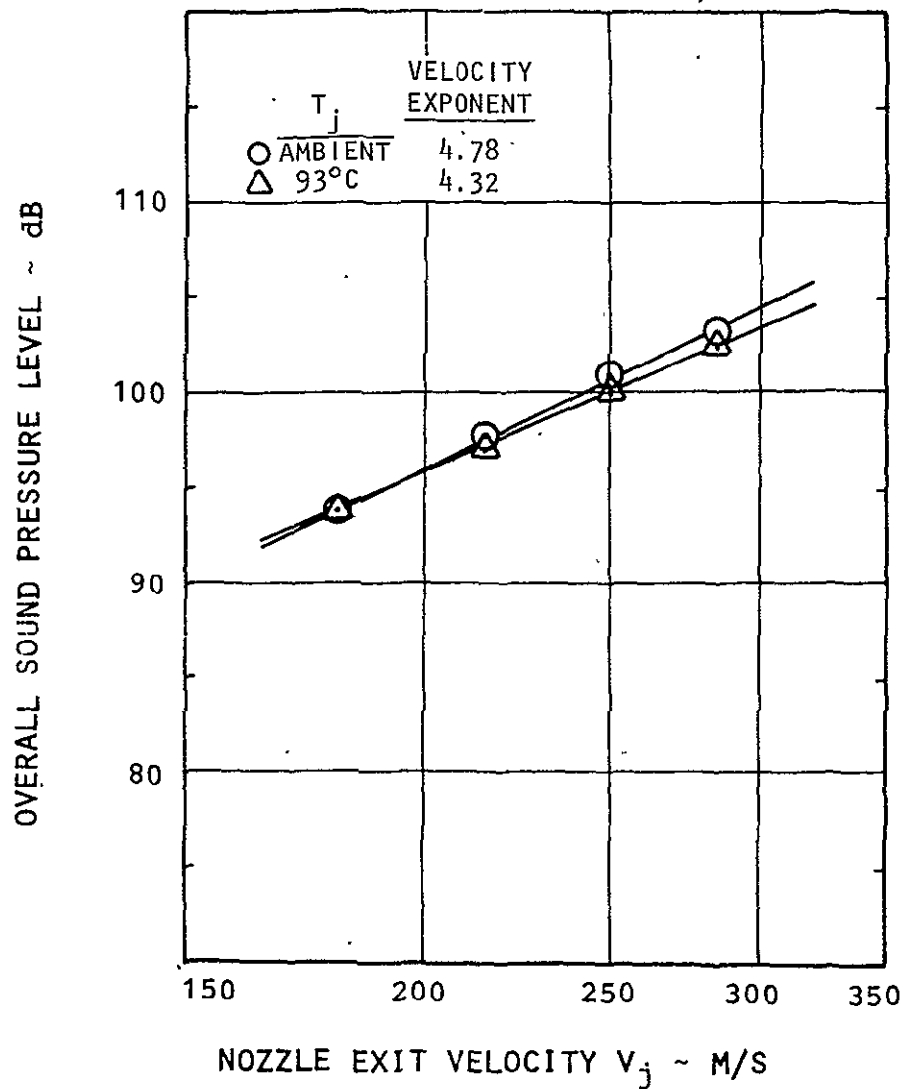


FIGURE 4-54. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

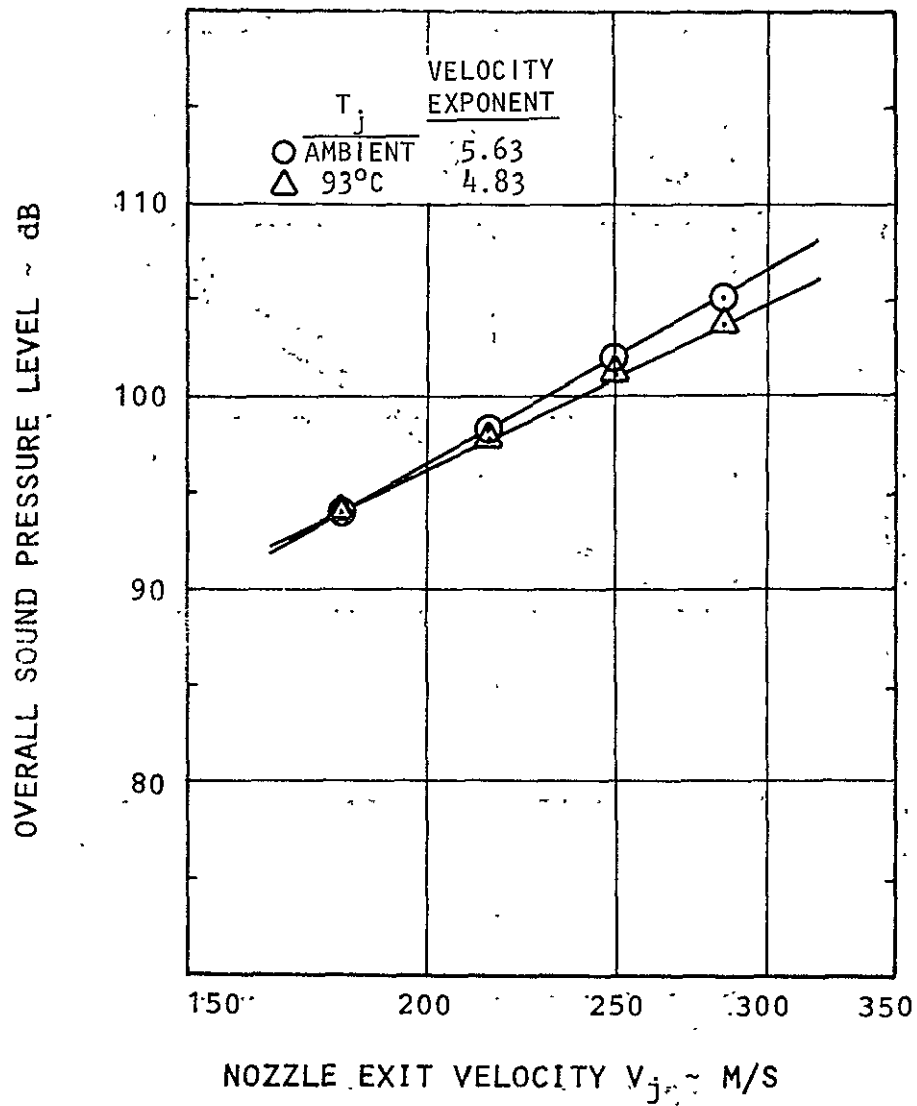
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-55. EFFECT OF JET TEMPERATURE ON VELOCITY EXPONENT

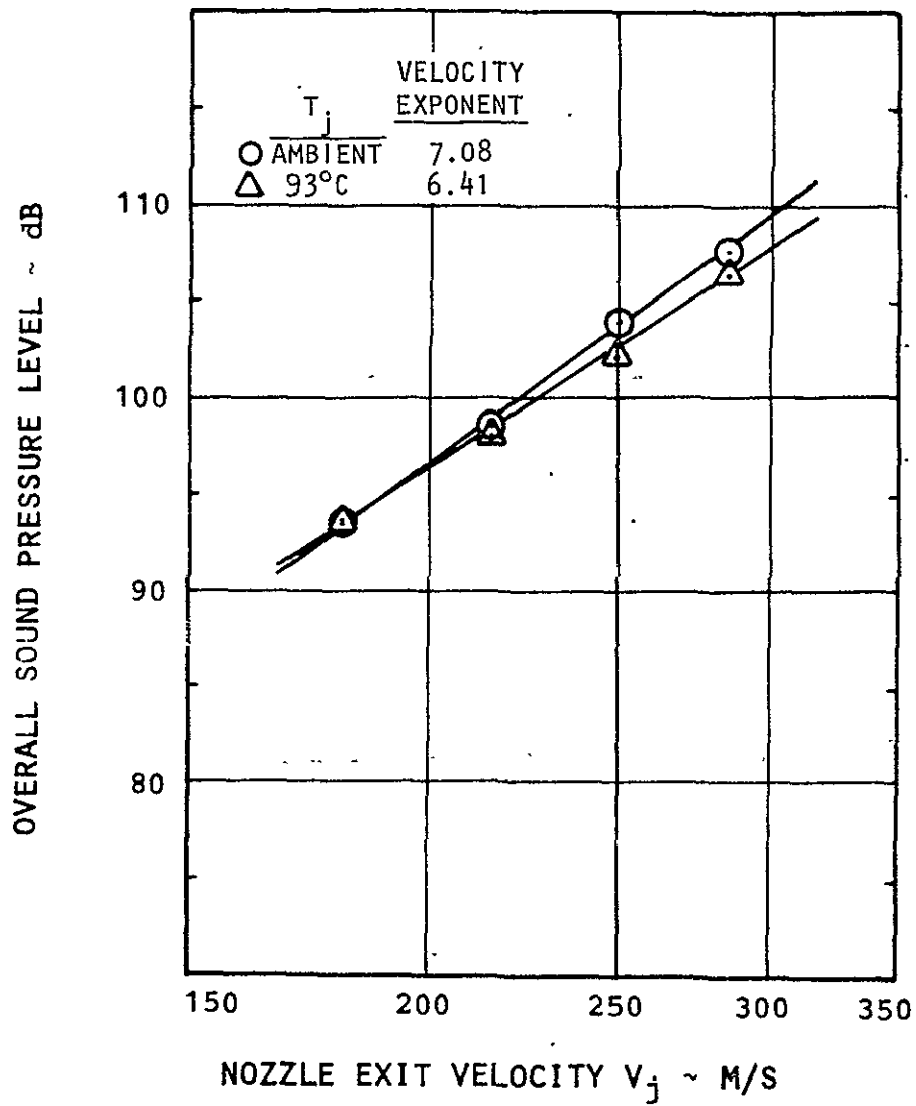
SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



b) $\theta = 90^\circ$

FIGURE 4-55. (CONTINUED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS



c) $\theta = 120^\circ$

FIGURE 4-55. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

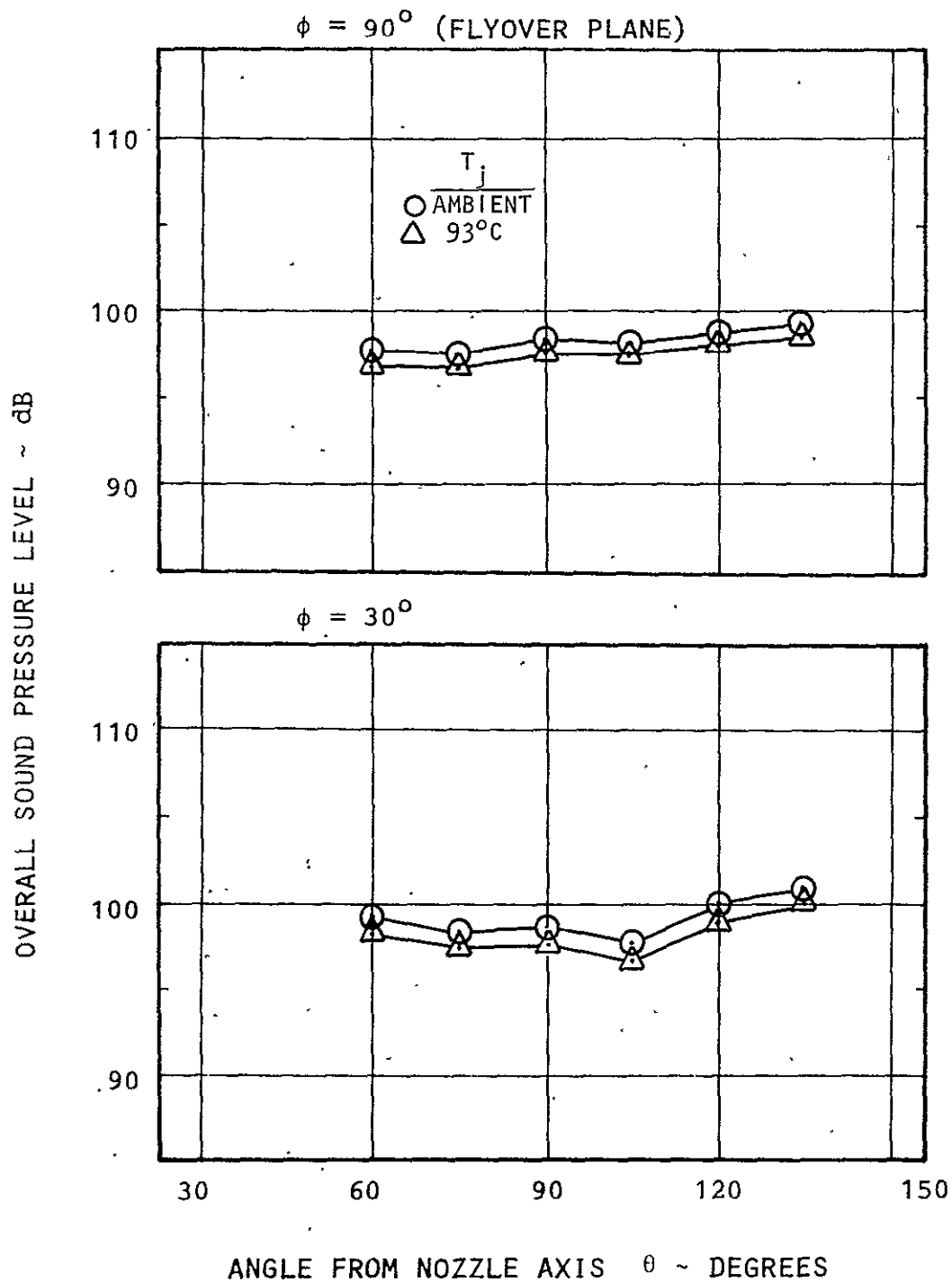


FIGURE 4-56. EFFECT OF JET TEMPERATURE ON DIRECTIVITY

NOZZLE ALONE MODEL DATA AT 6.1 METERS RADIUS

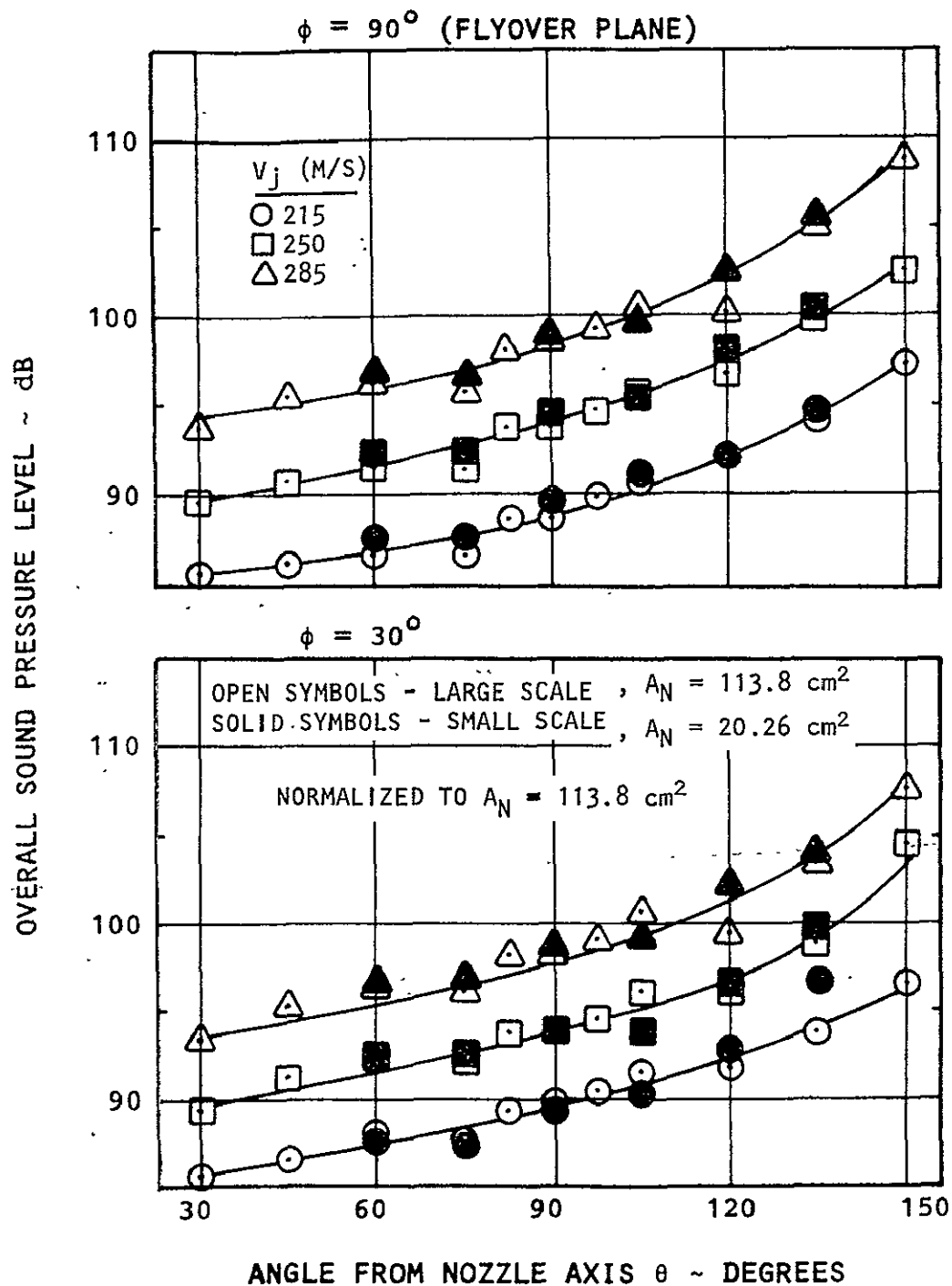


FIGURE 4-57. EFFECT OF MODEL SCALE ON DIRECTIVITY

NOZZLE ALONE MODEL DATA AT 6.1 METERS RADIUS

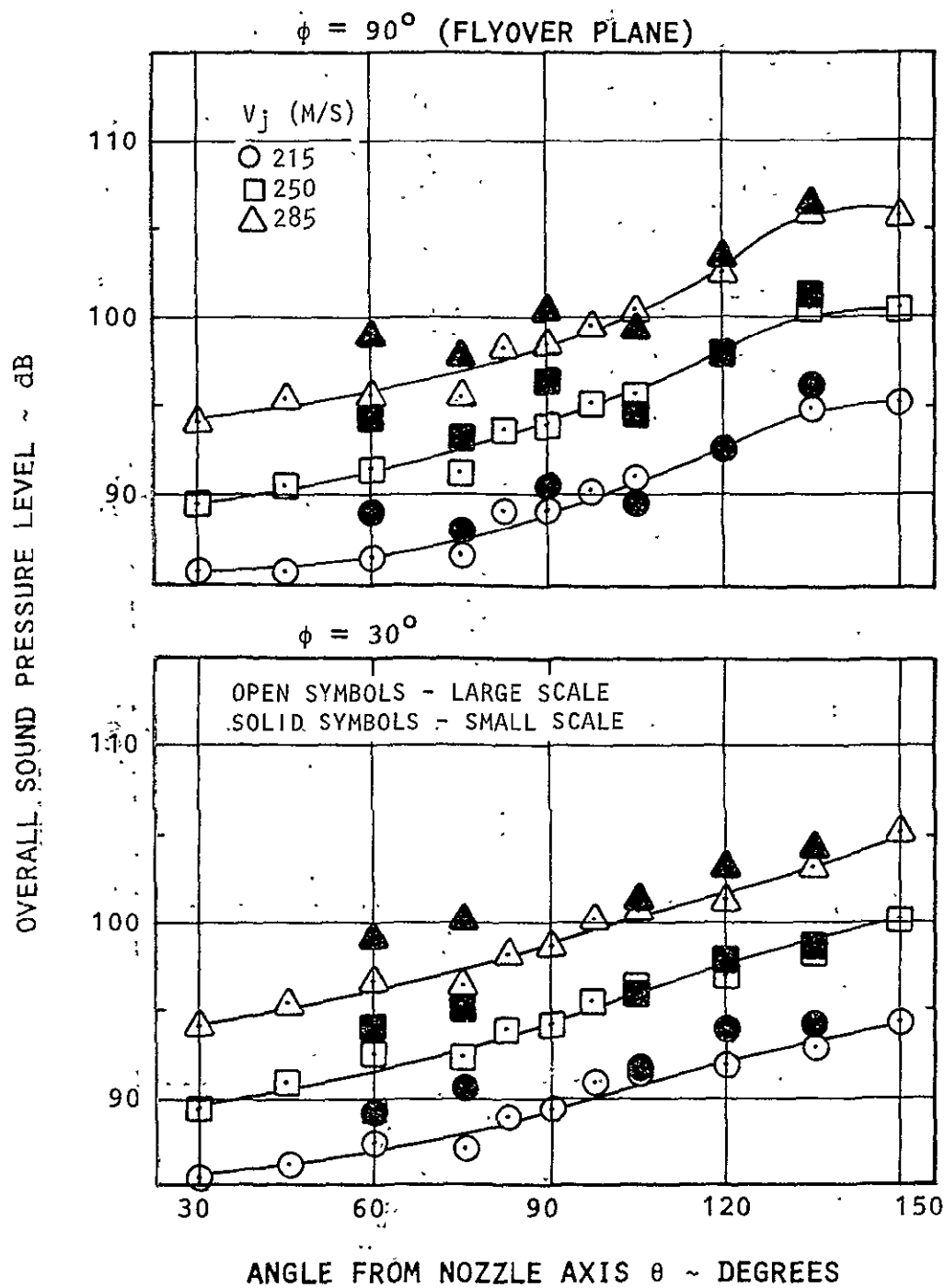
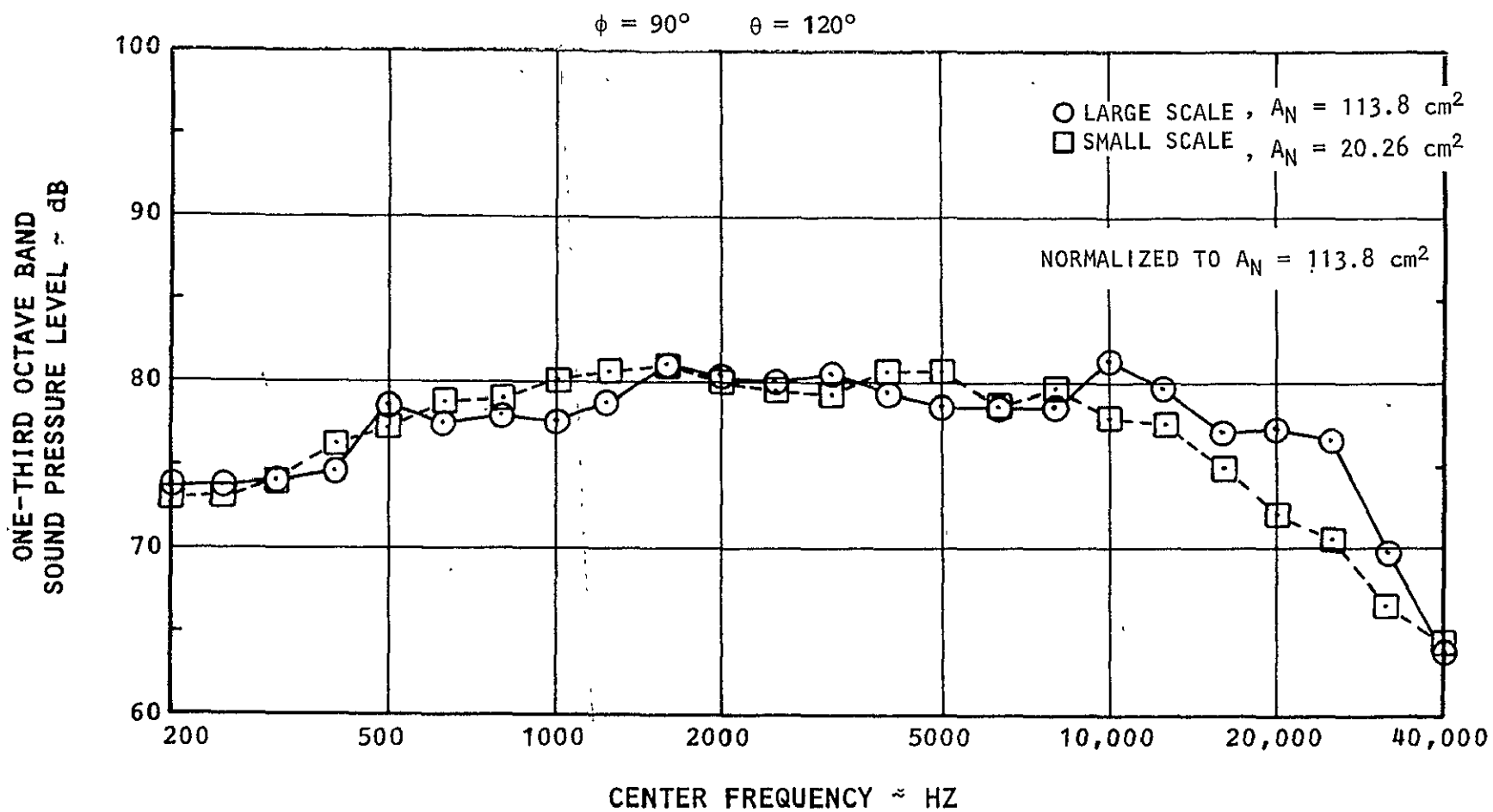


FIGURE 4-57. (CONCLUDED)

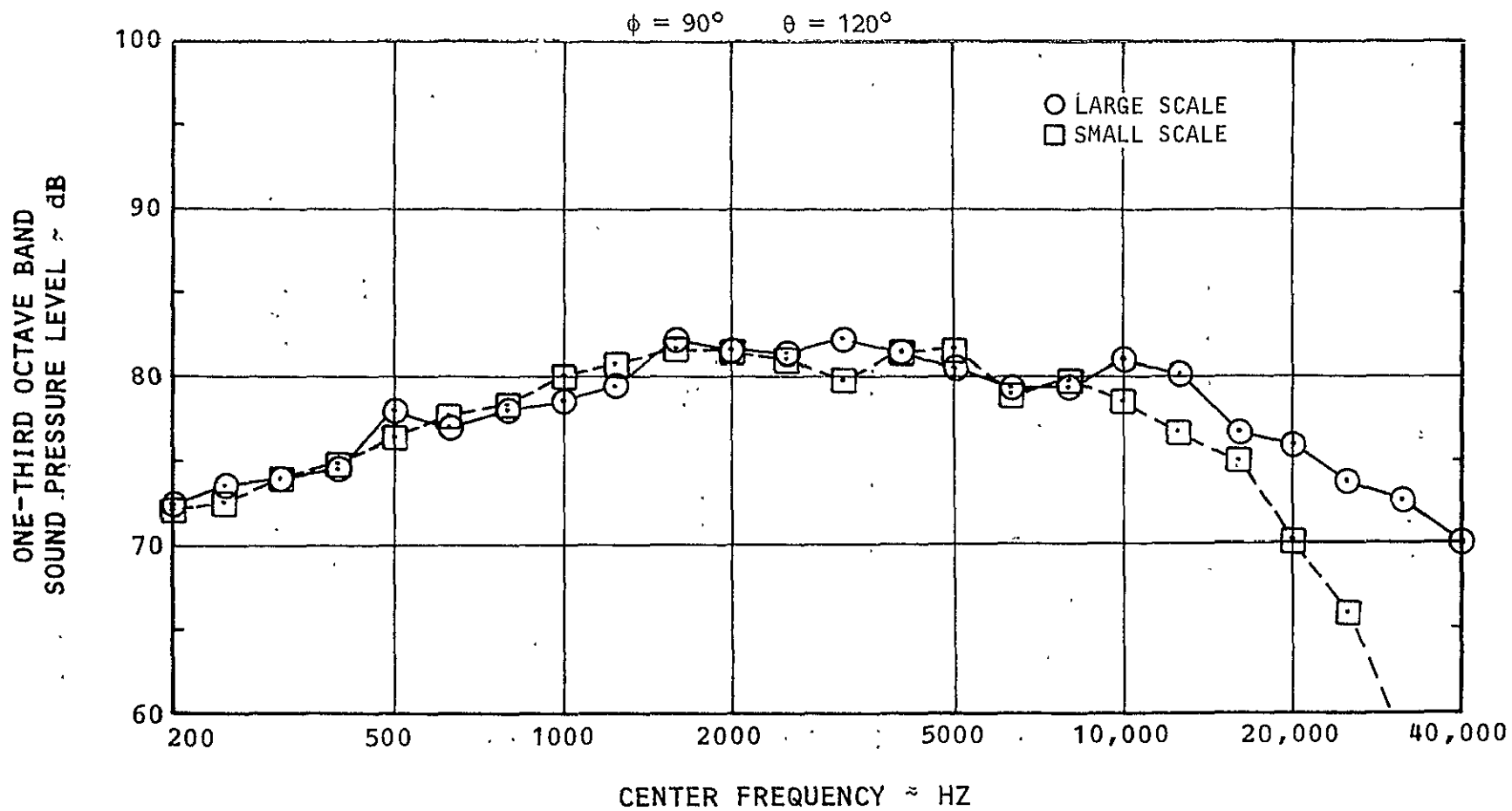
NOZZLE ALONE MODEL DATA AT 6.1 METERS RADIUS



a) AR4 NOZZLE

FIGURE 4-58. EFFECT OF MODEL SCALE ON SPECTRUM

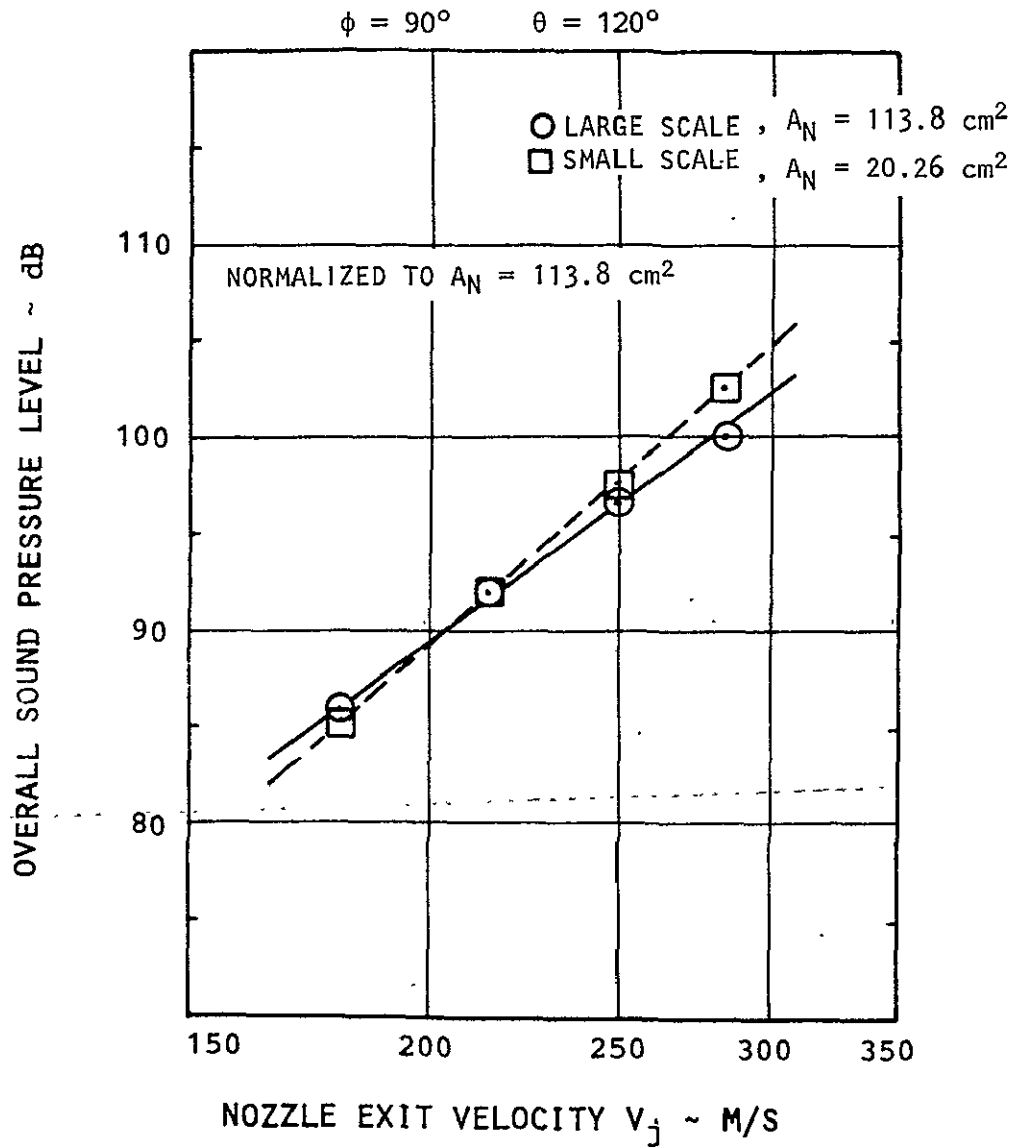
NOZZLE ALONE MODEL DATA AT 6.1 METERS RADIUS



b) AR8 NOZZLE

FIGURE 4-58. CONCLUDED

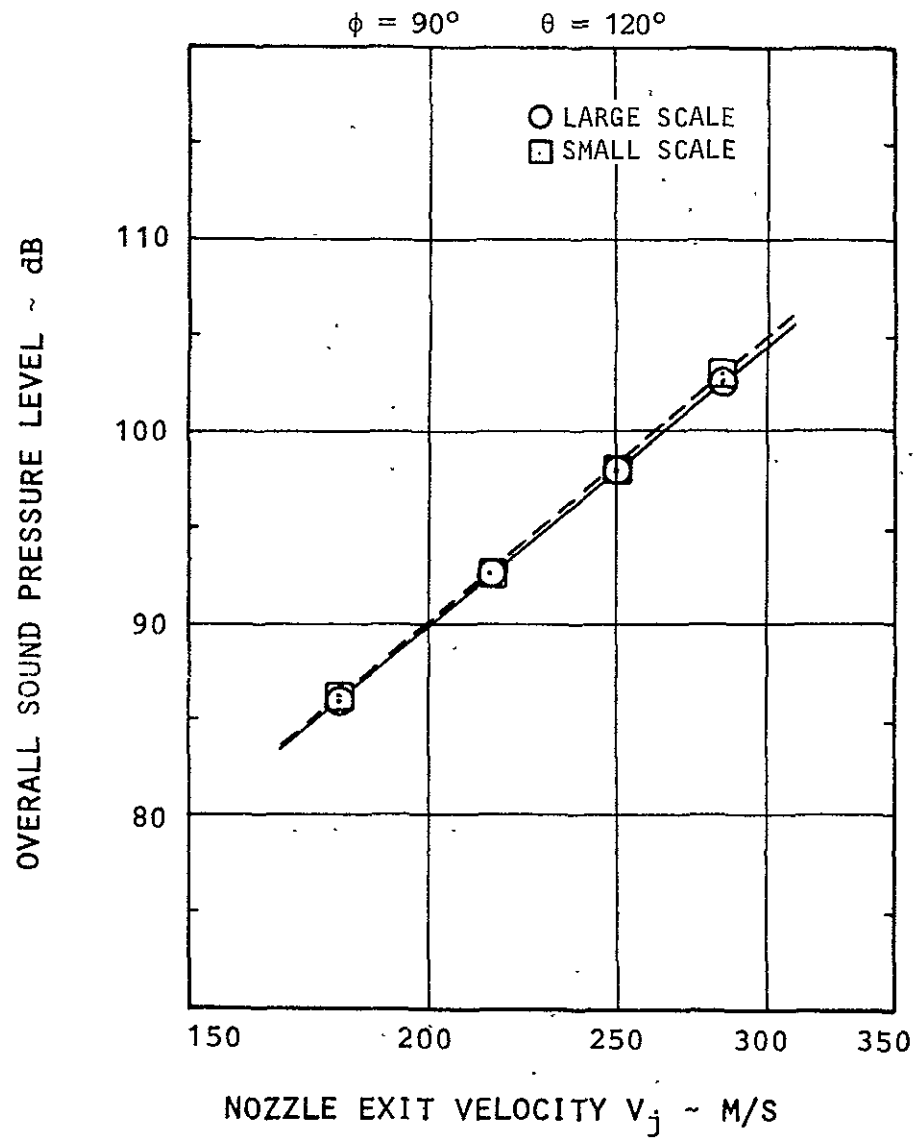
NOZZLE ALONE MODEL DATA AT 6.1 METERS RADIUS



a) AR4 NOZZLE

FIGURE 4-59. EFFECT OF MODEL SCALE ON VELOCITY EXPONENT

NOZZLE ALONE MODEL DATA AT 6.1 METERS RADIUS

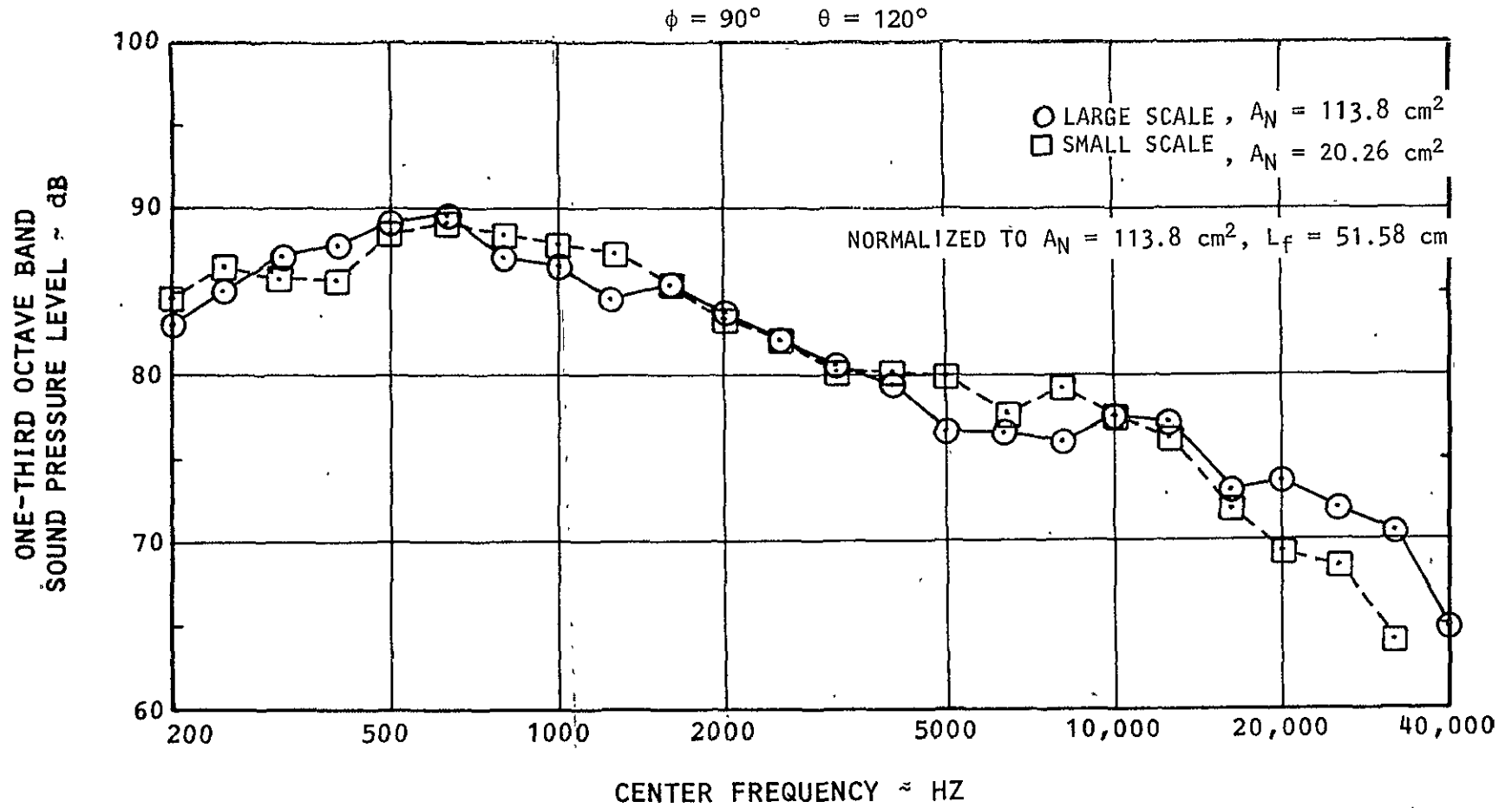


b) AR8 NOZZLE

FIGURE 4-59. (CONCLUDED)

NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS

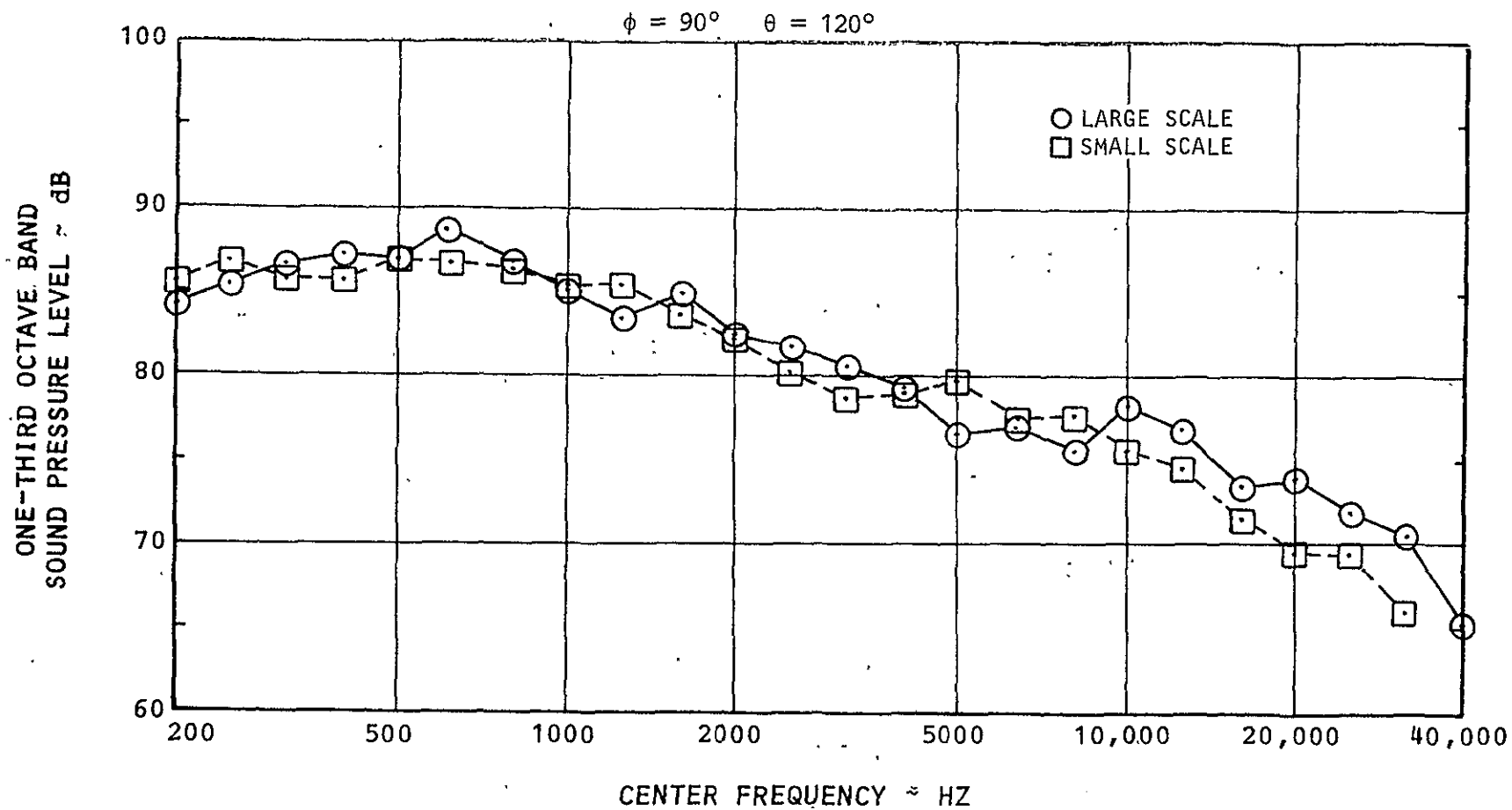
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) AR4 NOZZLE

FIGURE 4-60. EFFECT OF MODEL SCALE ON FLYOVER SPECTRUM

NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS

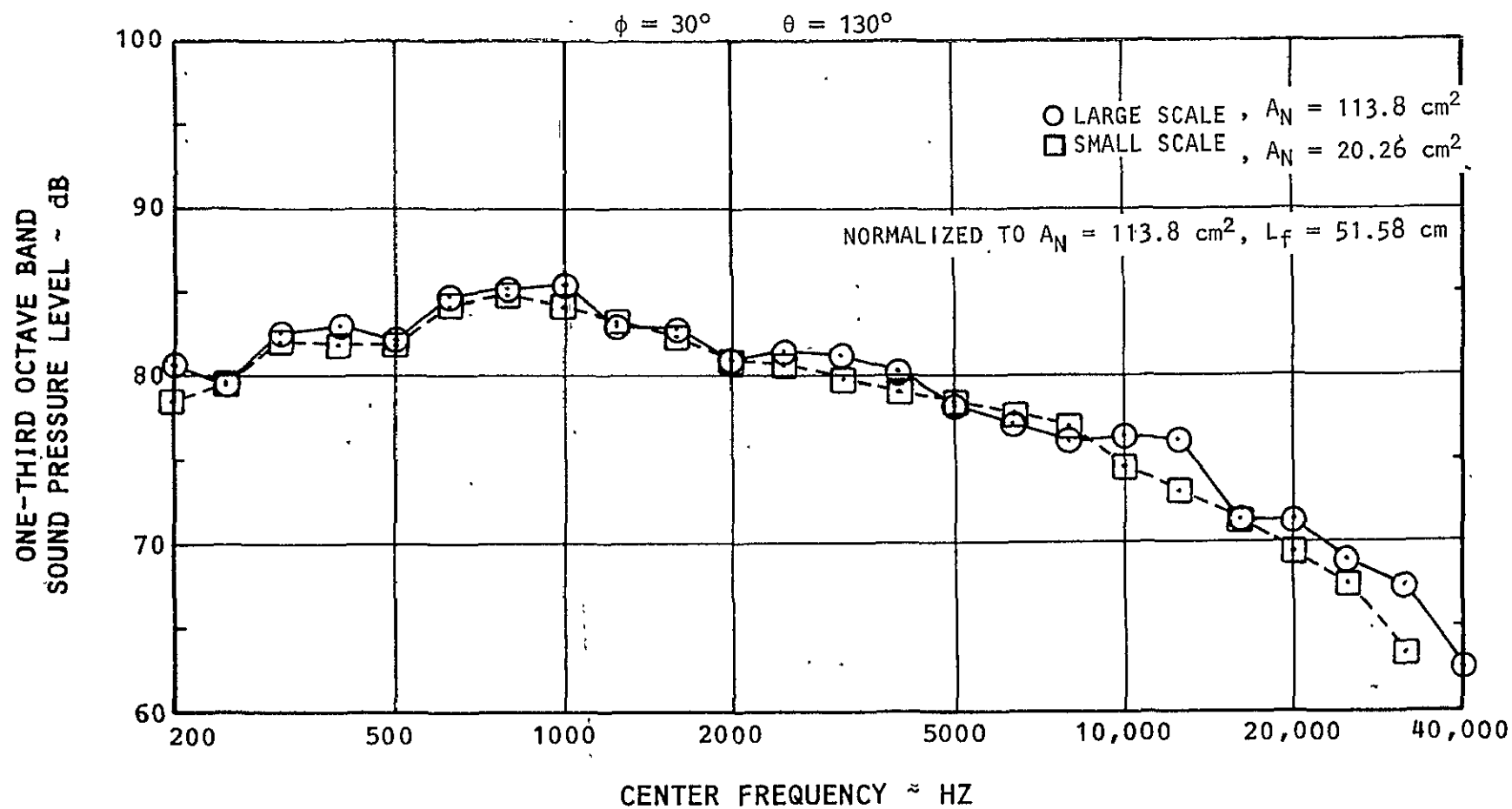


b) AR8 NOZZLE

FIGURE 4-60. (CONCLUDED)

NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS

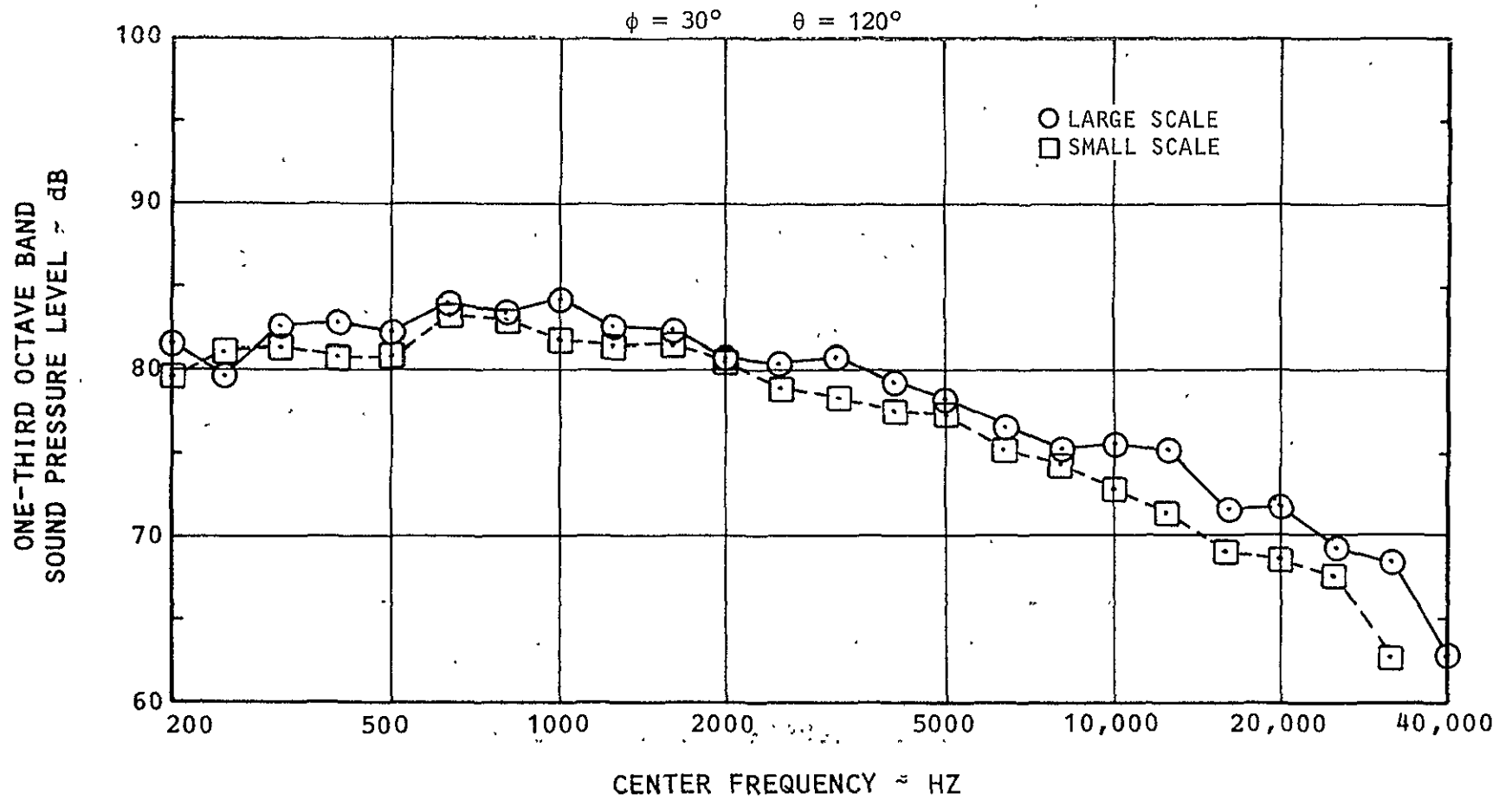
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) AR4 NOZZLE

FIGURE 4-61. EFFECT OF MODEL SCALE ON SIDELINE SPECTRUM

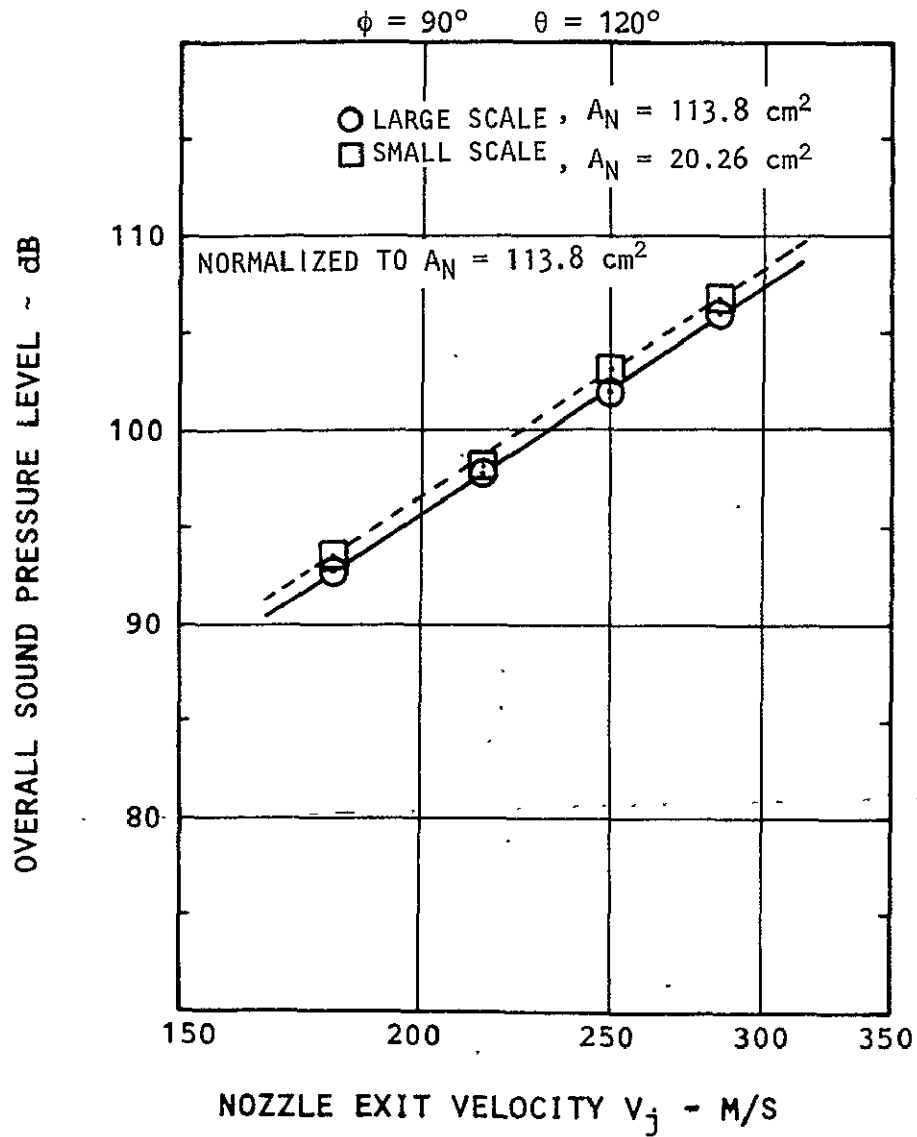
NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS



b) AR8 NOZZLE

FIGURE 4-61. (CONCLUDED)

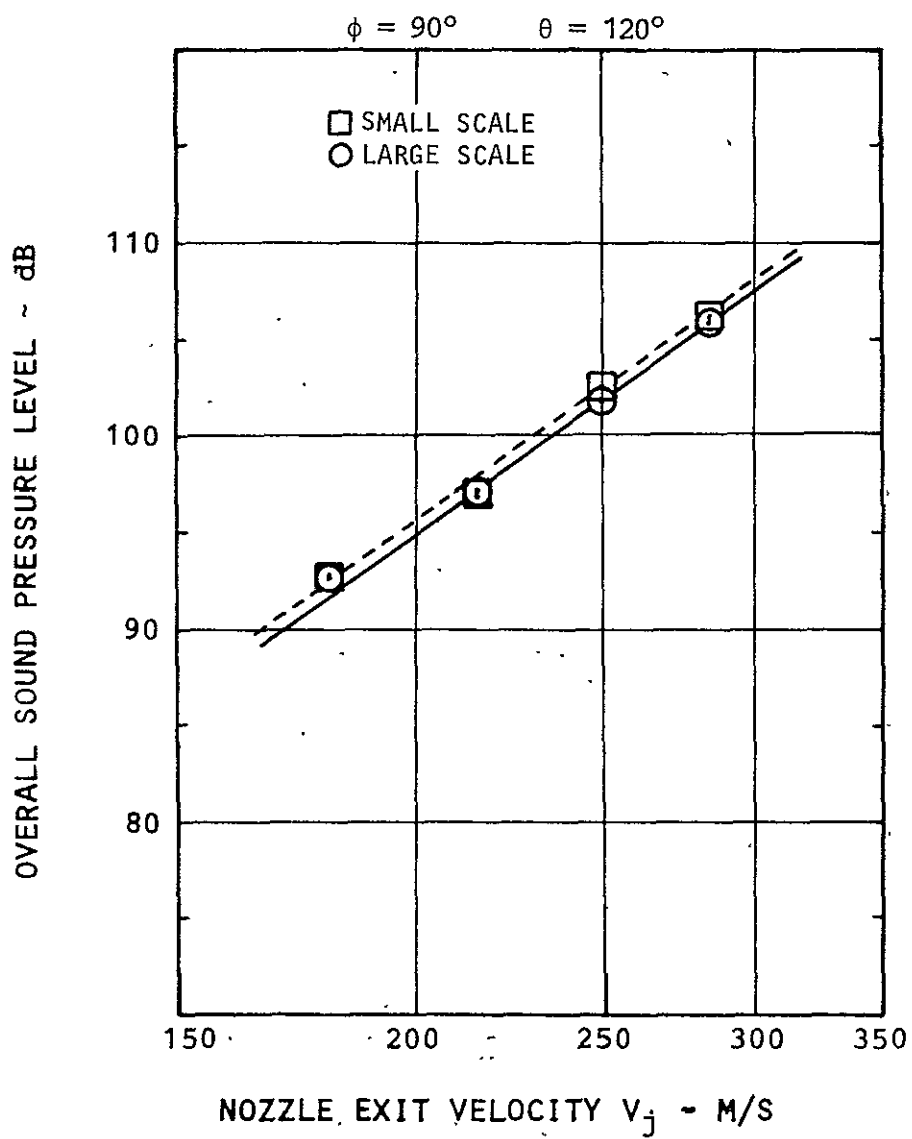
NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) AR $1/4$ NOZZLE

FIGURE 4-62. EFFECT OF MODEL SCALE ON FLYOVER VELOCITY EXPONENT

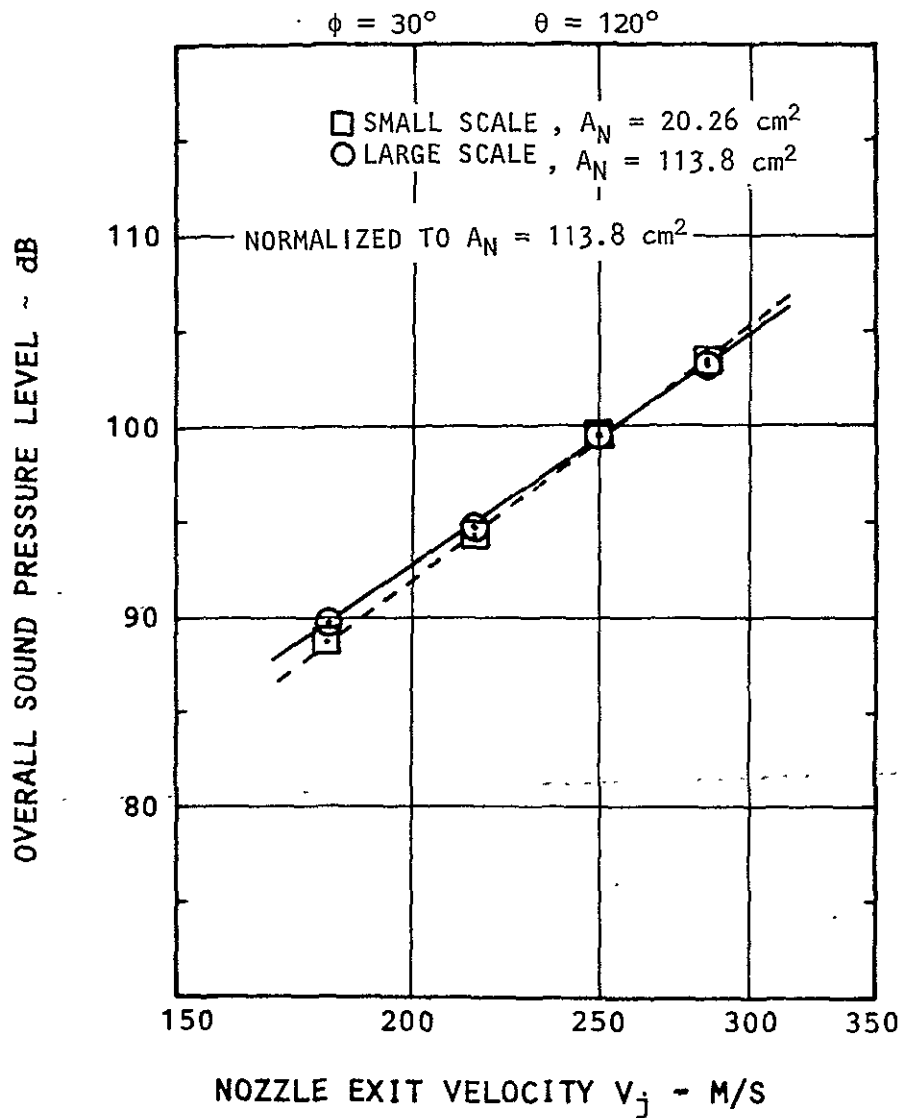
NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS



b) AR8 NOZZLE

FIGURE 4-62. (CONCLUDED)

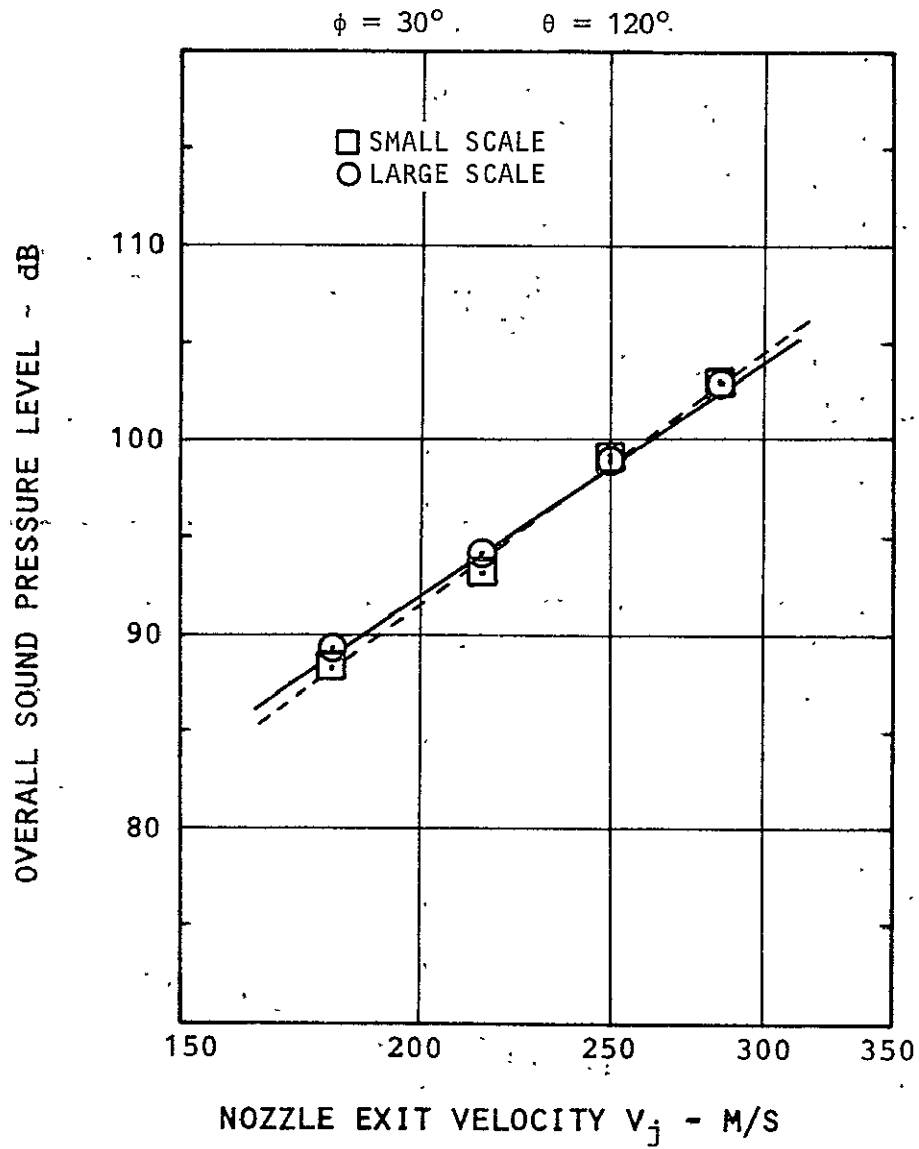
NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) AR 4 NOZZLE

FIGURE 4-63. EFFECT OF MODEL SCALE ON SIDELINE VELOCITY EXPONENT

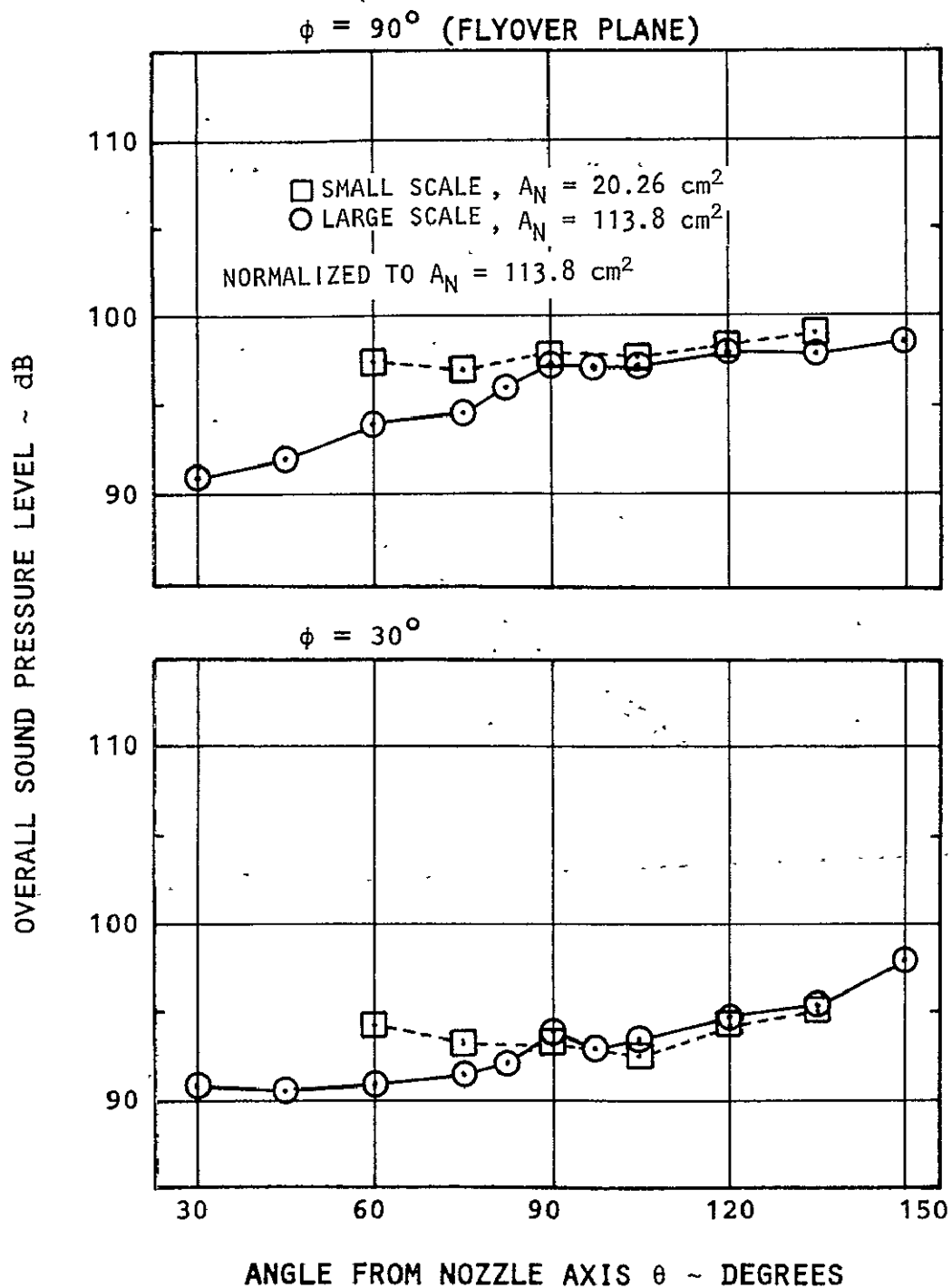
NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS



b) AR8 NOZZLE

FIGURE 4-63. (CONCLUDED)

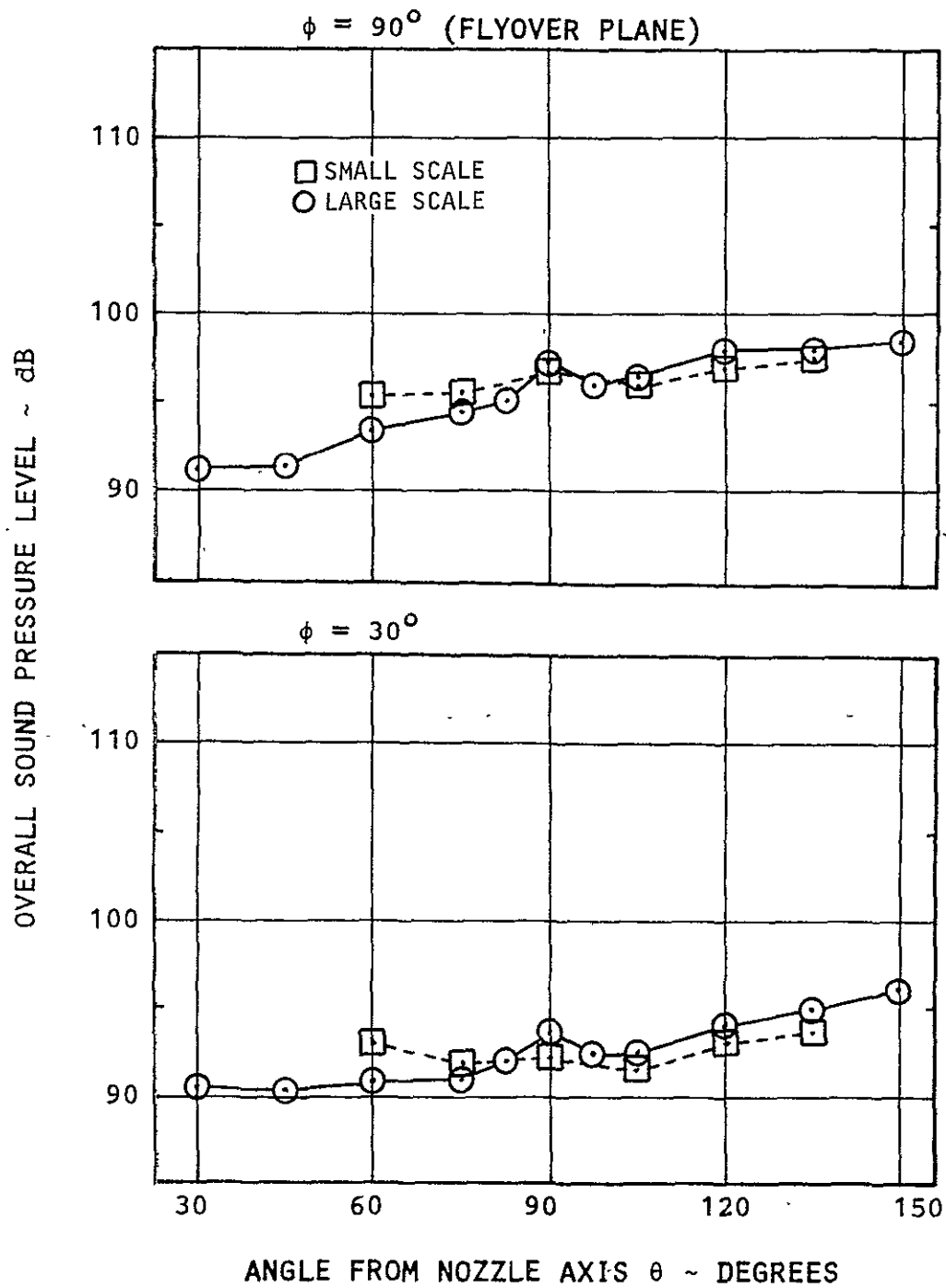
NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) AR4 NOZZLE

FIGURE 4-64. EFFECT OF MODEL SCALE ON DIRECTIVITY

NOZZLE & WING/FLAP DATA AT 6.1 METERS RADIUS



b) AR8 NOZZLE

FIGURE 4-64. (CONCLUDED)

FLYOVER MICROPHONE

MODEL DATA

$V_j = 250 \text{ M/S}$

AR-2 NOZZLE

$A_N = 10.13 \text{ cm}^2$

$\theta_N = 20^\circ$

$X_N = .20 \text{ C}$

$\delta f = 30^\circ$

$R_c = 5.08 \text{ cm}$

$L_{te} = 6.48 \text{ cm}$

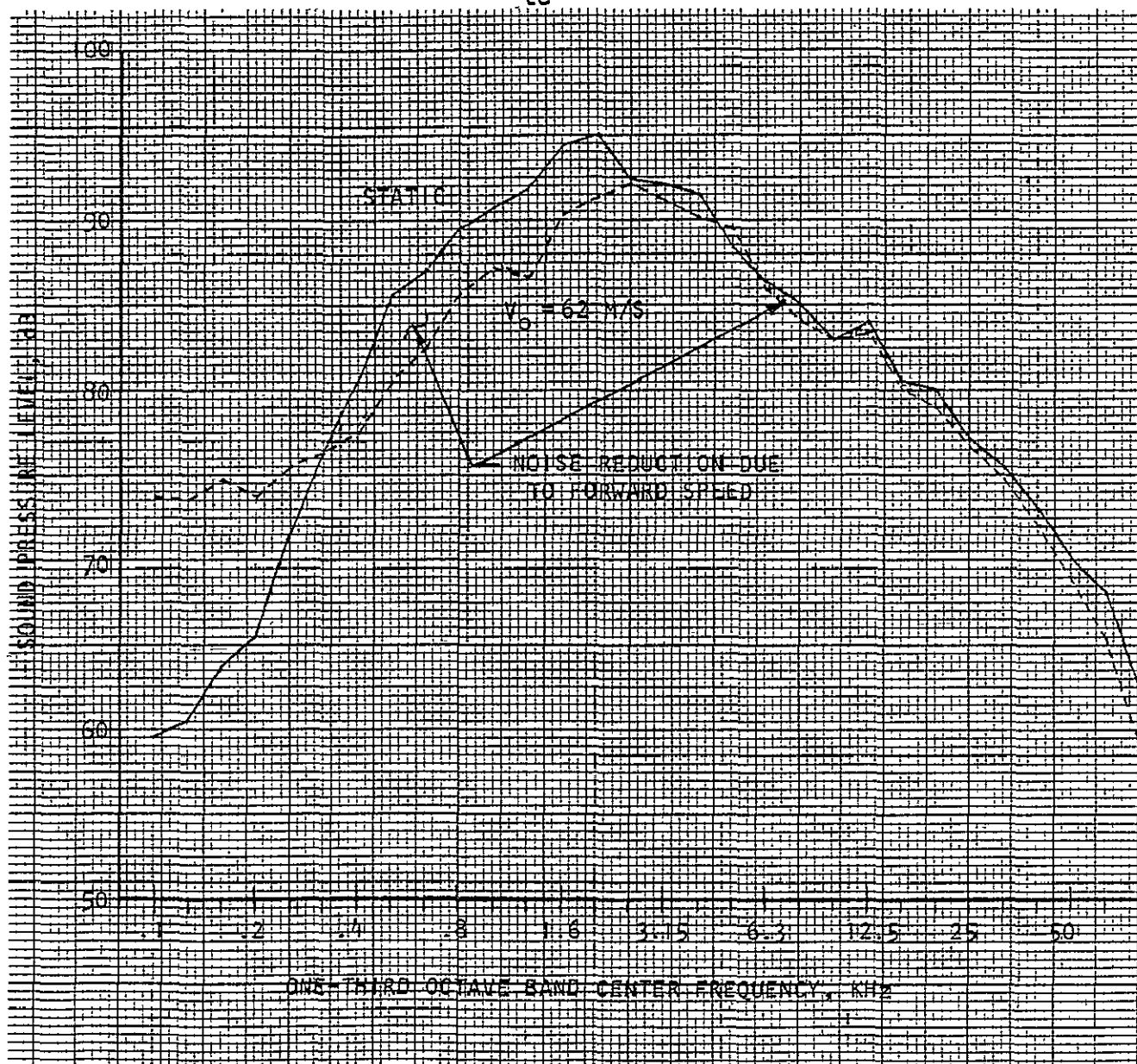
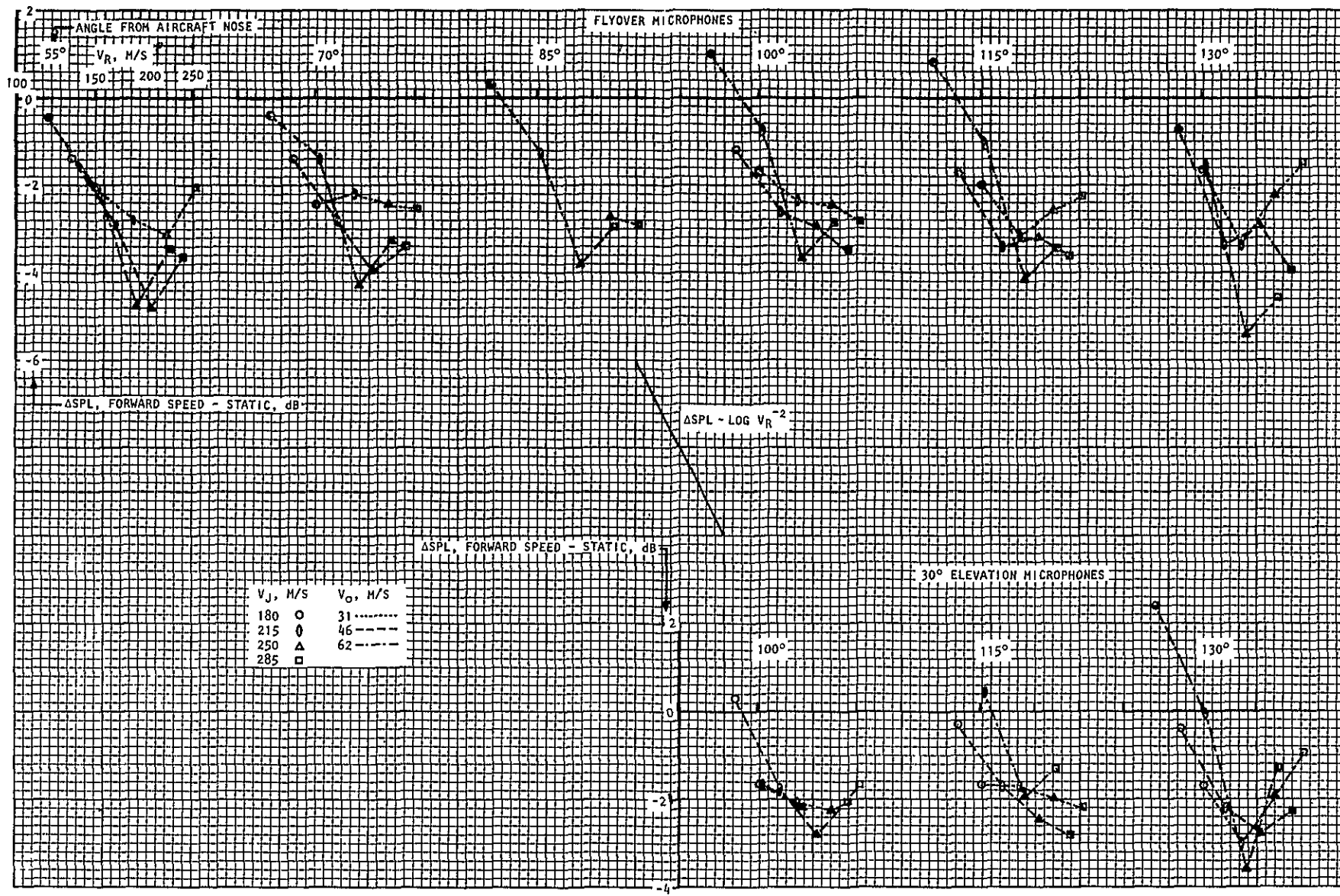
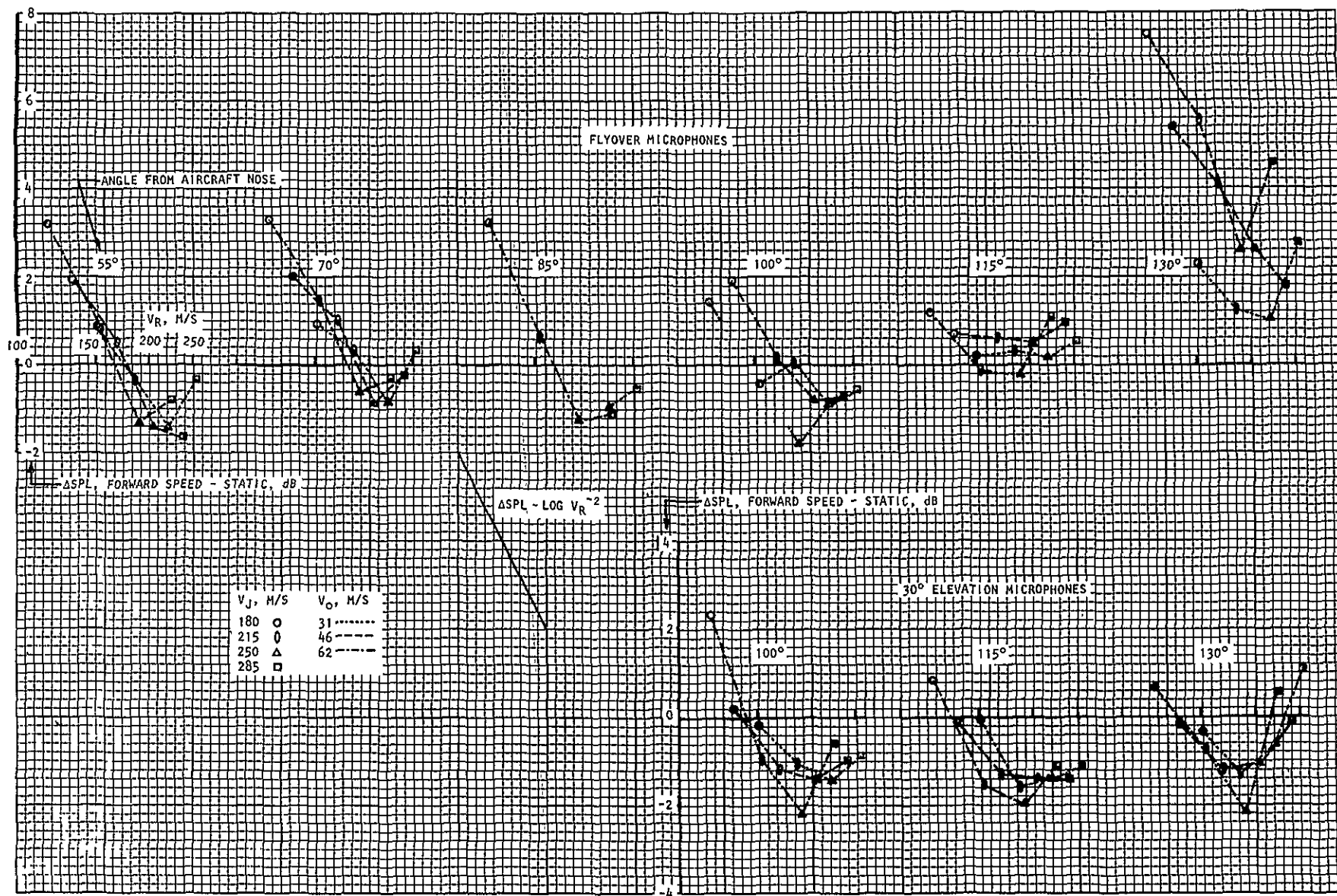


FIGURE 4-65. EFFECT OF FORWARD SPEED ON SPECTRUM



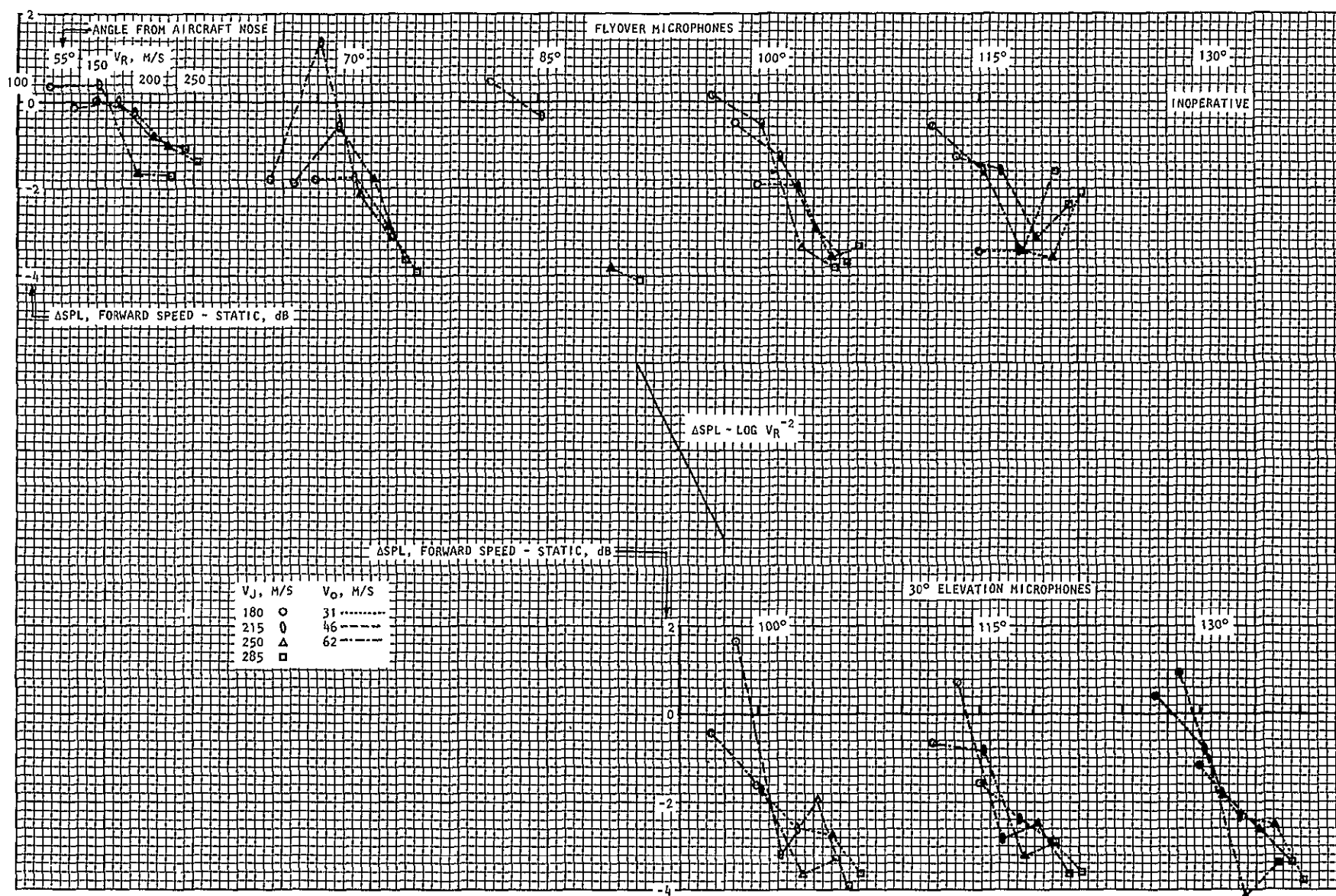
(A) $\delta_F = 30^\circ$; $L_{T.E.} = 6.48$ CM; NOZZLE/WING GAP = 0. LOW FREQUENCIES.

FIGURE 4-66. NOISE INCREMENTS DUE TO FORWARD SPEED.
 NOZZLE — AR-2; 10.13 CM^2 ; $\theta_N = 20^\circ$; $X_N = .20C$.
 WING — $B = 50.80 \text{ CM}$; $C = 15.24 \text{ CM}$. FLAP — $R_C = 5.08 \text{ CM}$.



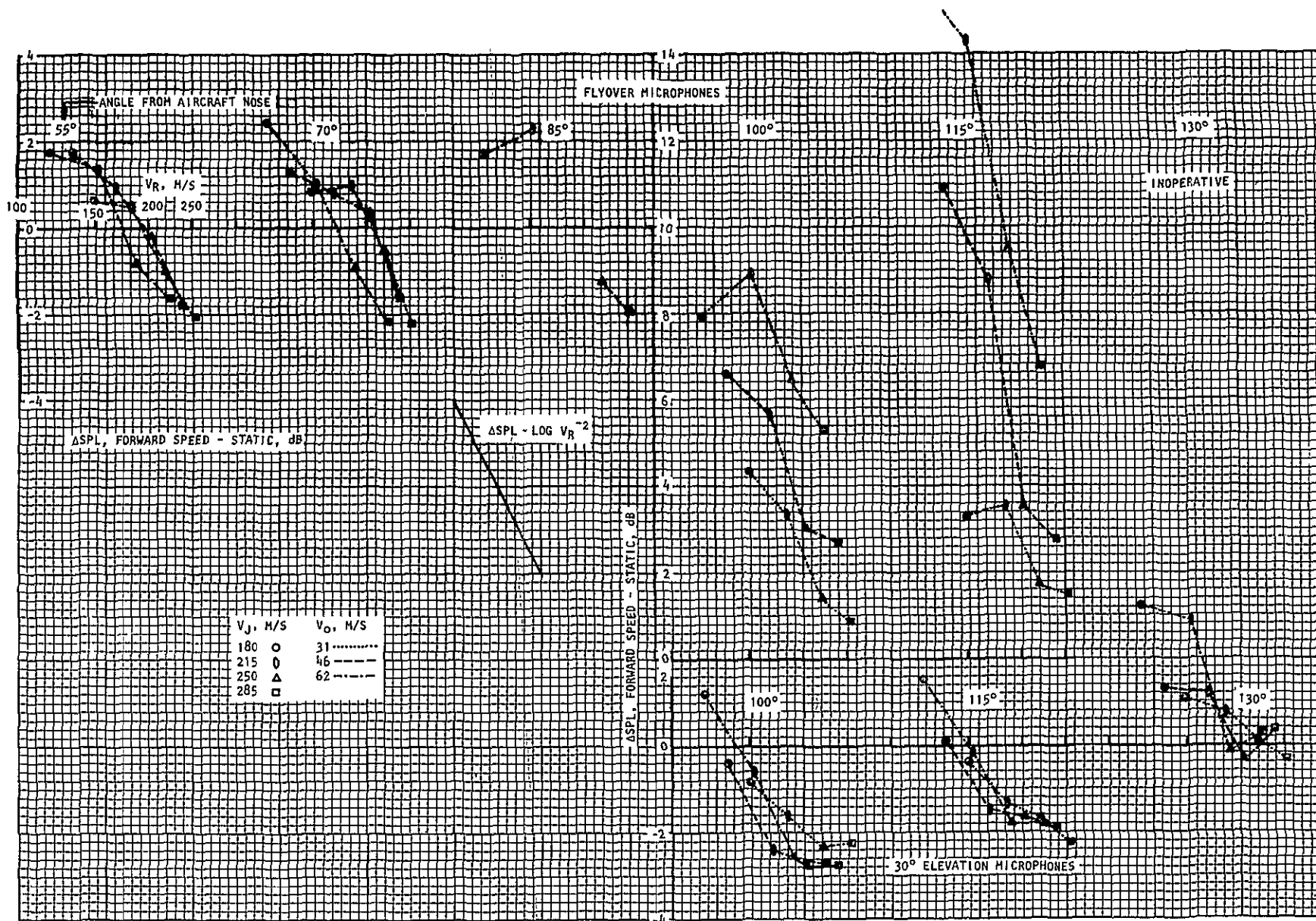
(B) $\delta_F = 30^\circ$; $L_{T.E.} = 6.48$ CM; NOZZLE/WING GAP = 0. HIGH FREQUENCIES.

FIGURE 4-66. CONTINUED.



(C) $\delta_F = 60^\circ$; $L_{T.E.} = 3.81$ CM; NOZZLE/WING GAP = 0. LOW FREQUENCIES.

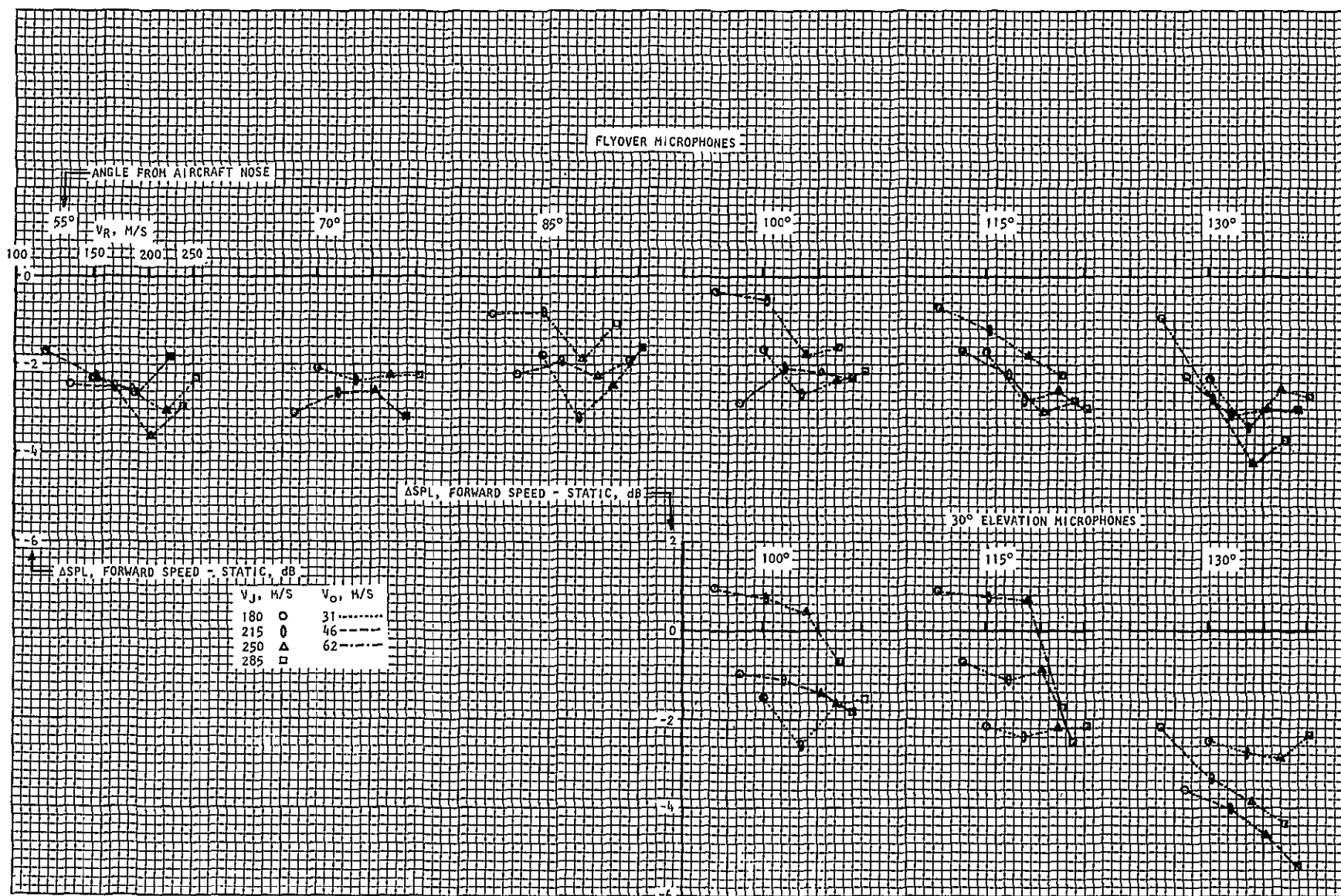
FIGURE 4-66. CONTINUED.



(D) $\delta_F = 60^\circ$; $L_{T.E.} = 3.81$ CM; NOZZLE/WING GAP ≈ 0 . HIGH FREQUENCIES.

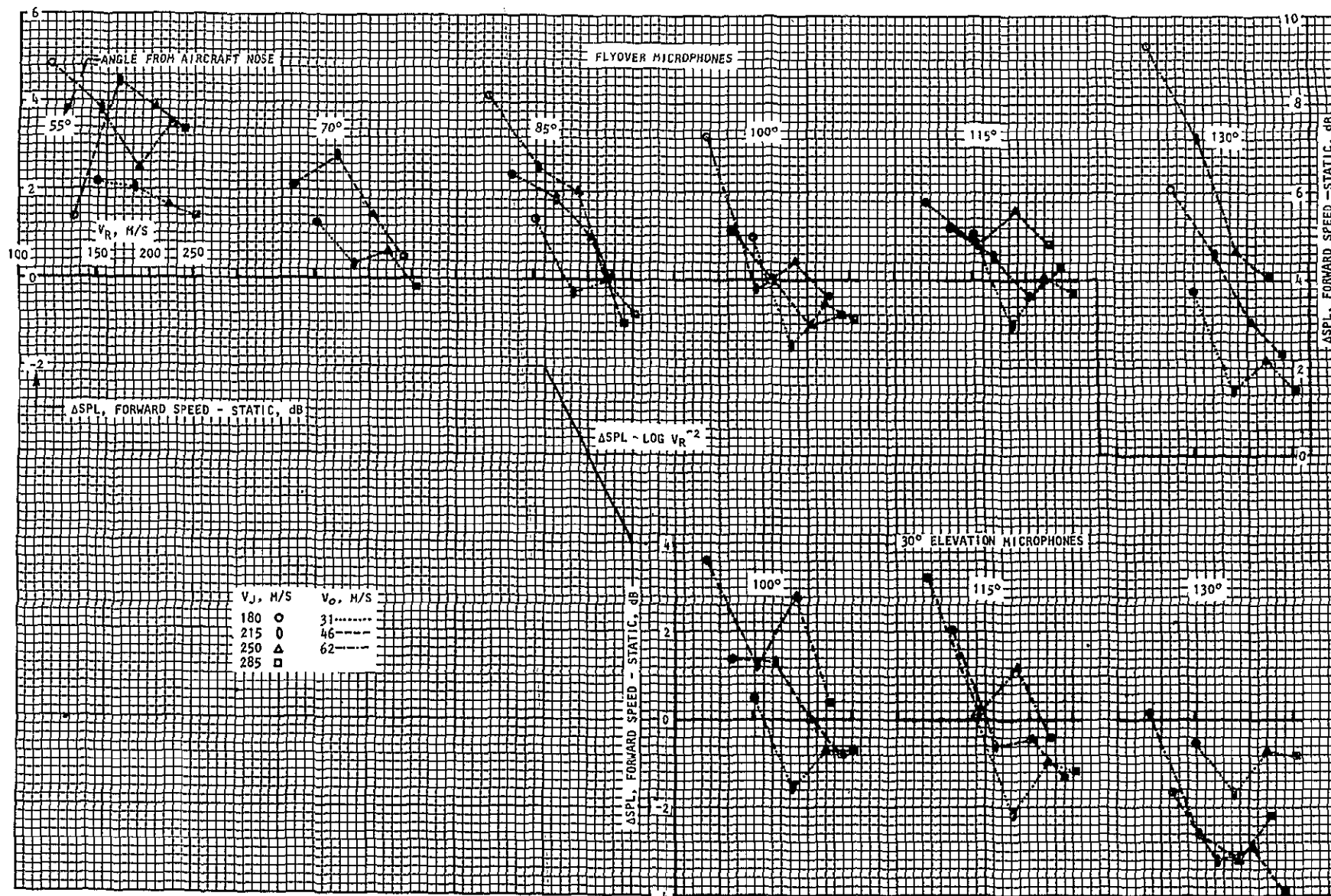
FIGURE 4-66. CONTINUED.

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OF POOR QUALITY



(E) $\delta_F = 30^\circ$; $L_{T.E.} = 6.48$ CM; NOZZLE/WING GAP = .76 CM. LOW FREQUENCY.

FIGURE 4-66. CONTINUED.



(F) $\delta_F = 30^\circ$; $L_{T.E.} = 6.48$ CM; NOZZLE/WING GAP = .76 CM. HIGH FREQUENCIES.

FIGURE 4-66. CONCLUDED.

ANGLE FROM AIRCRAFT NOSE = 115°

ELEVATION ANGLE = 90°

MODEL DATA

$V_J = 215 \text{ M/S}$

AR-2 NOZZLE

$A_N = 10.13 \text{ cm}^2$

$\theta_N = 20^\circ$

$X_N = .20 \text{ C}$

$\delta_f = 60^\circ$

$R_C = 5.08 \text{ cm}$

$L_{te} = 3.81 \text{ cm}$

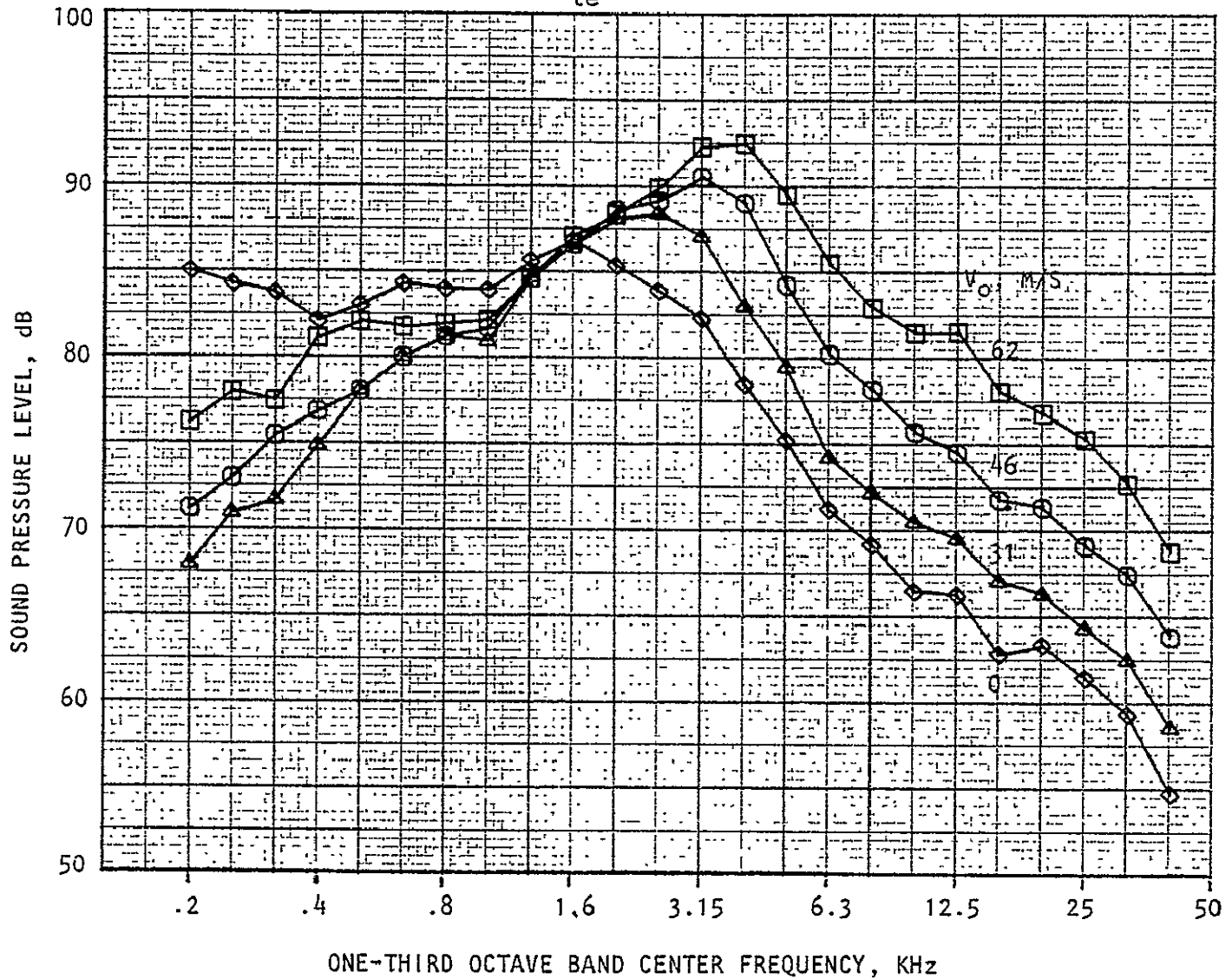


FIGURE 4-67 EXAMPLE OF INCREASE IN HIGH FREQUENCY NOISE AT AFT MICROPHONE WITH INCREASING FORWARD SPEED.

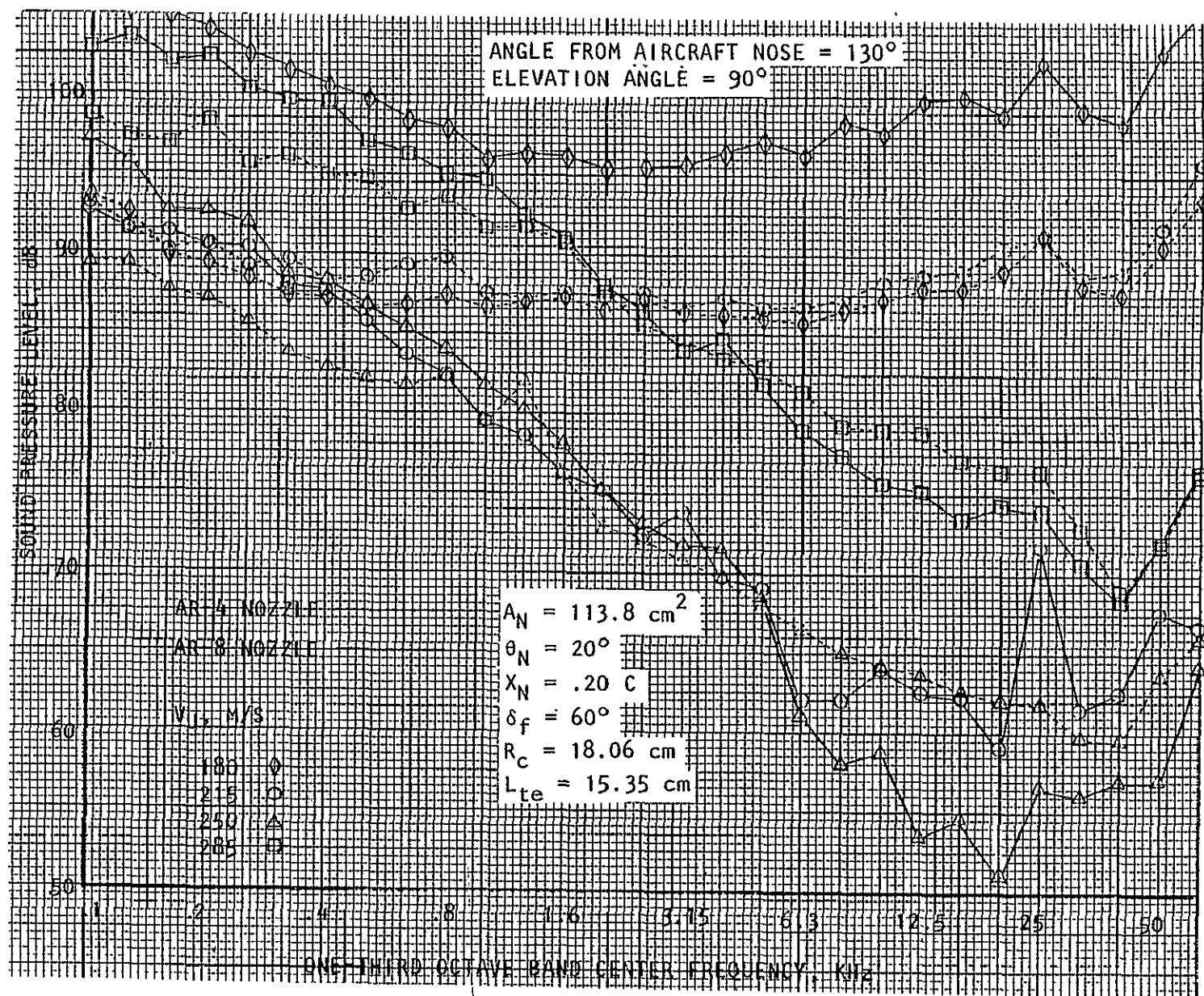
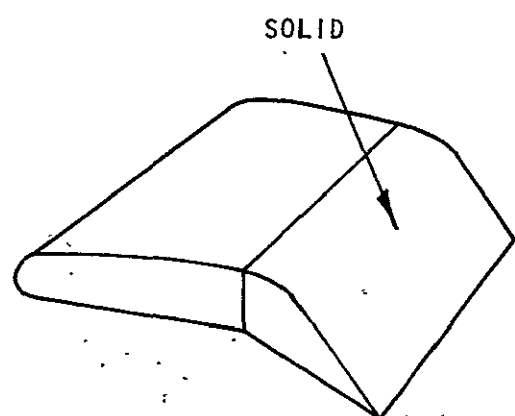
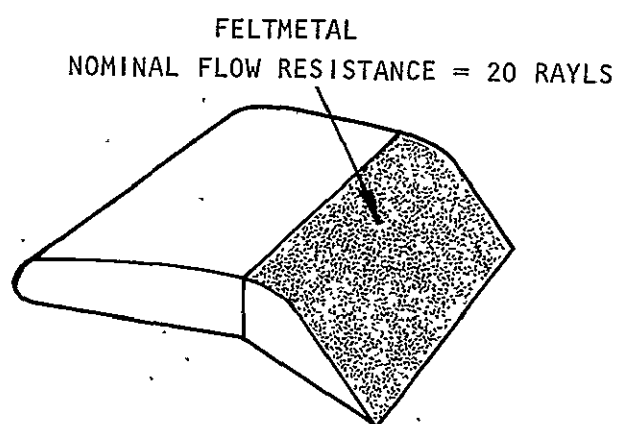


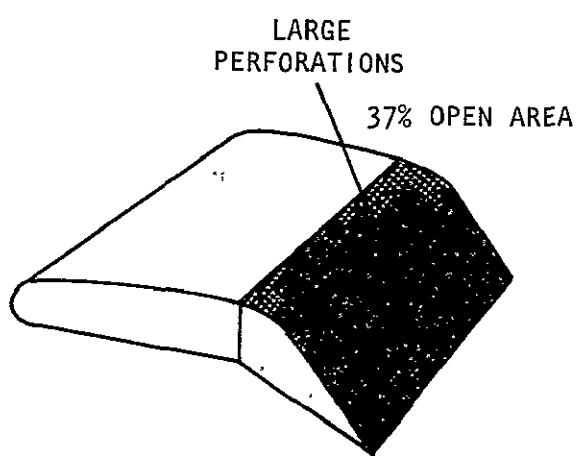
FIGURE 4-68. SPECTRA FROM MICROPHONE IN DEFLECTED JET; LARGE SCALE TEST RIG



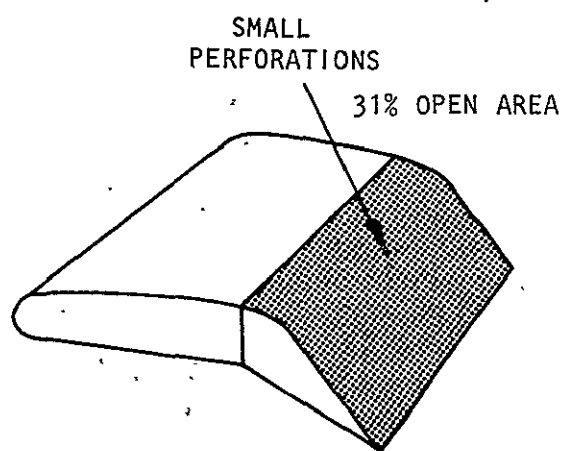
CONFIGURATION 1



CONFIGURATION 2

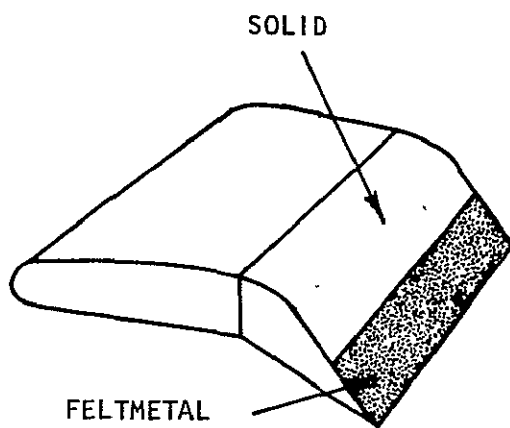


CONFIGURATION 3

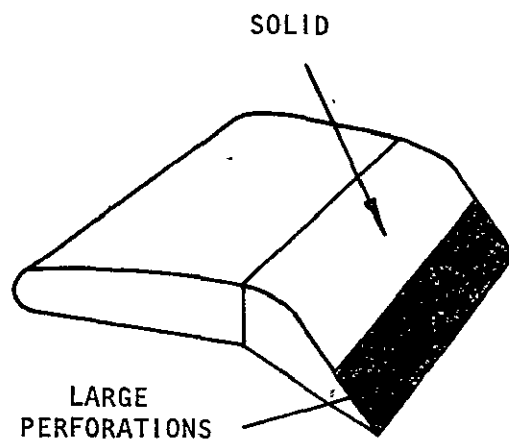


CONFIGURATION 4

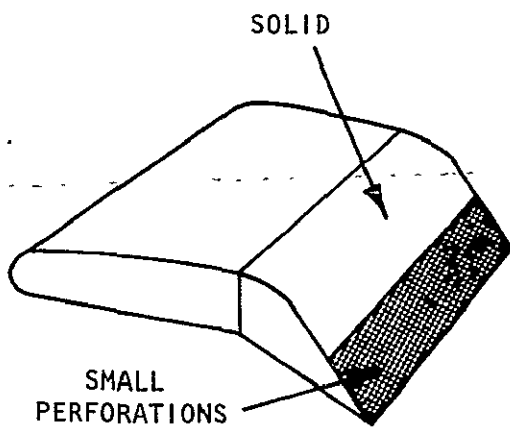
FIGURE 4-69. NOISE REDUCTION CONFIGURATIONS



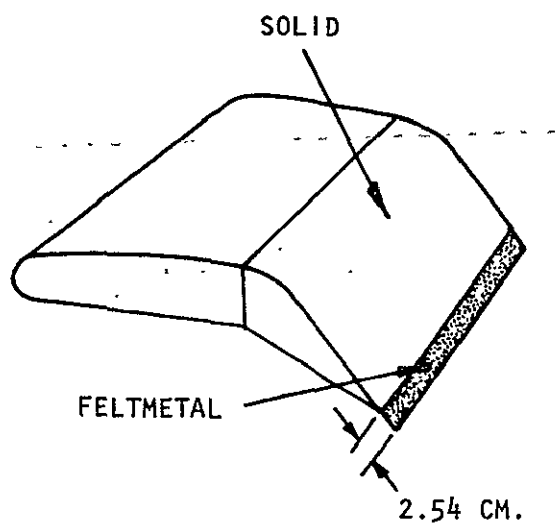
CONFIGURATION 5



CONFIGURATION 6

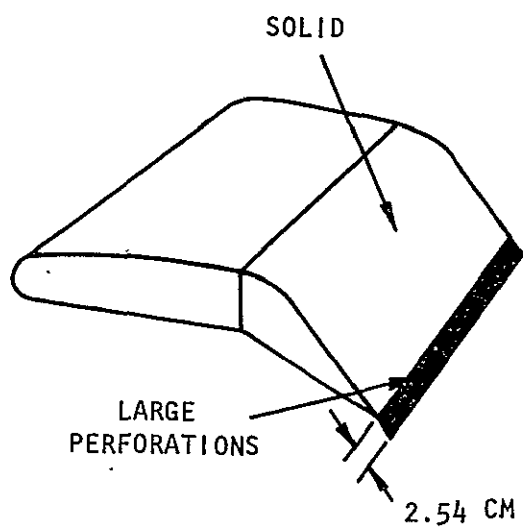


CONFIGURATION 7

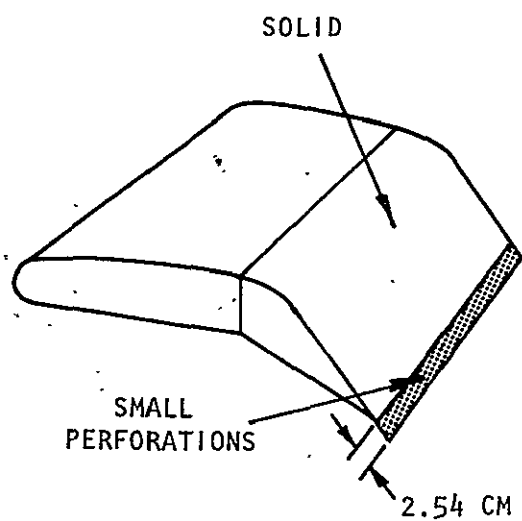


CONFIGURATION 8

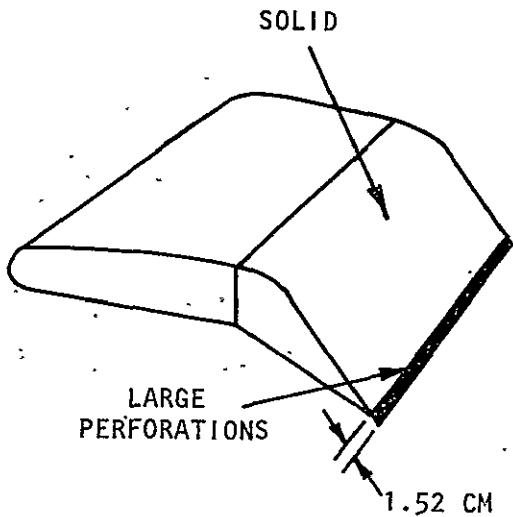
FIGURE 4-69. (CONTINUED)



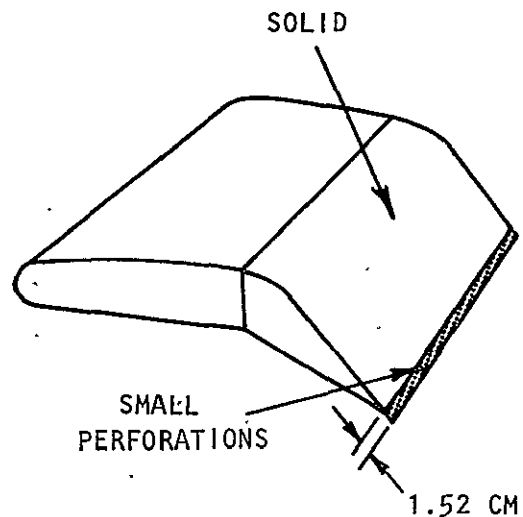
CONFIGURATION 9



CONFIGURATION 10

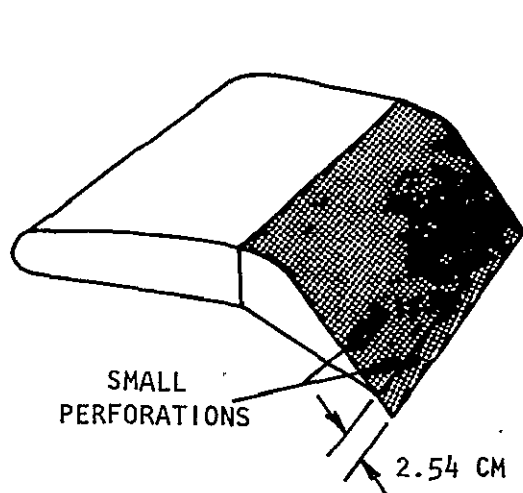


CONFIGURATION 11

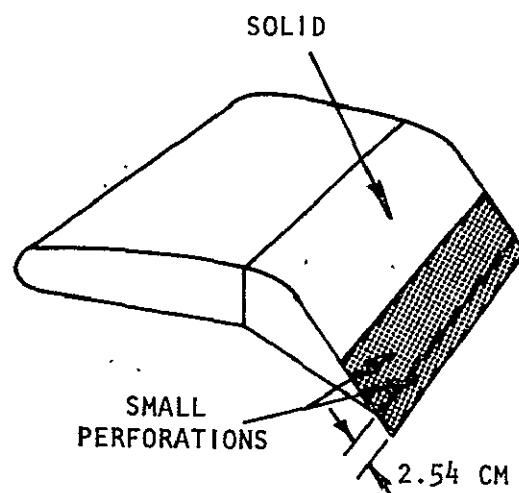


CONFIGURATION 12

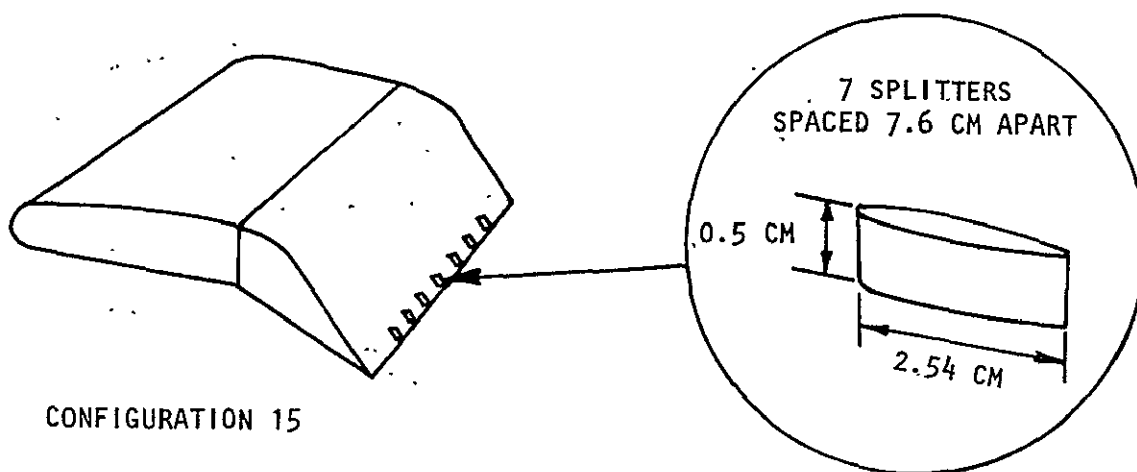
FIGURE 4-69. (CONTINUED)



CONFIGURATION 13



CONFIGURATION 14

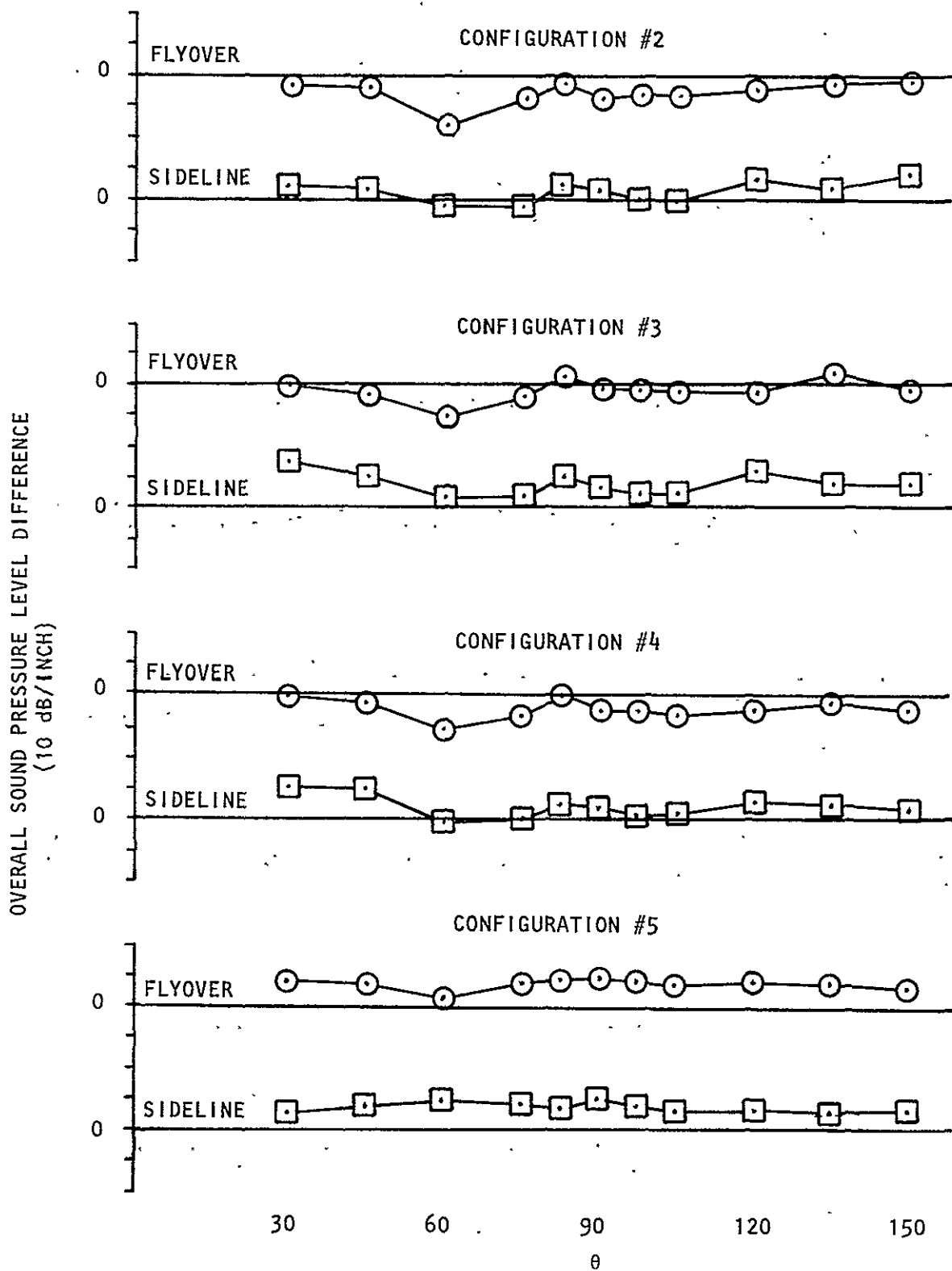


CONFIGURATION 15

FIGURE 4-69. (CONCLUDED)

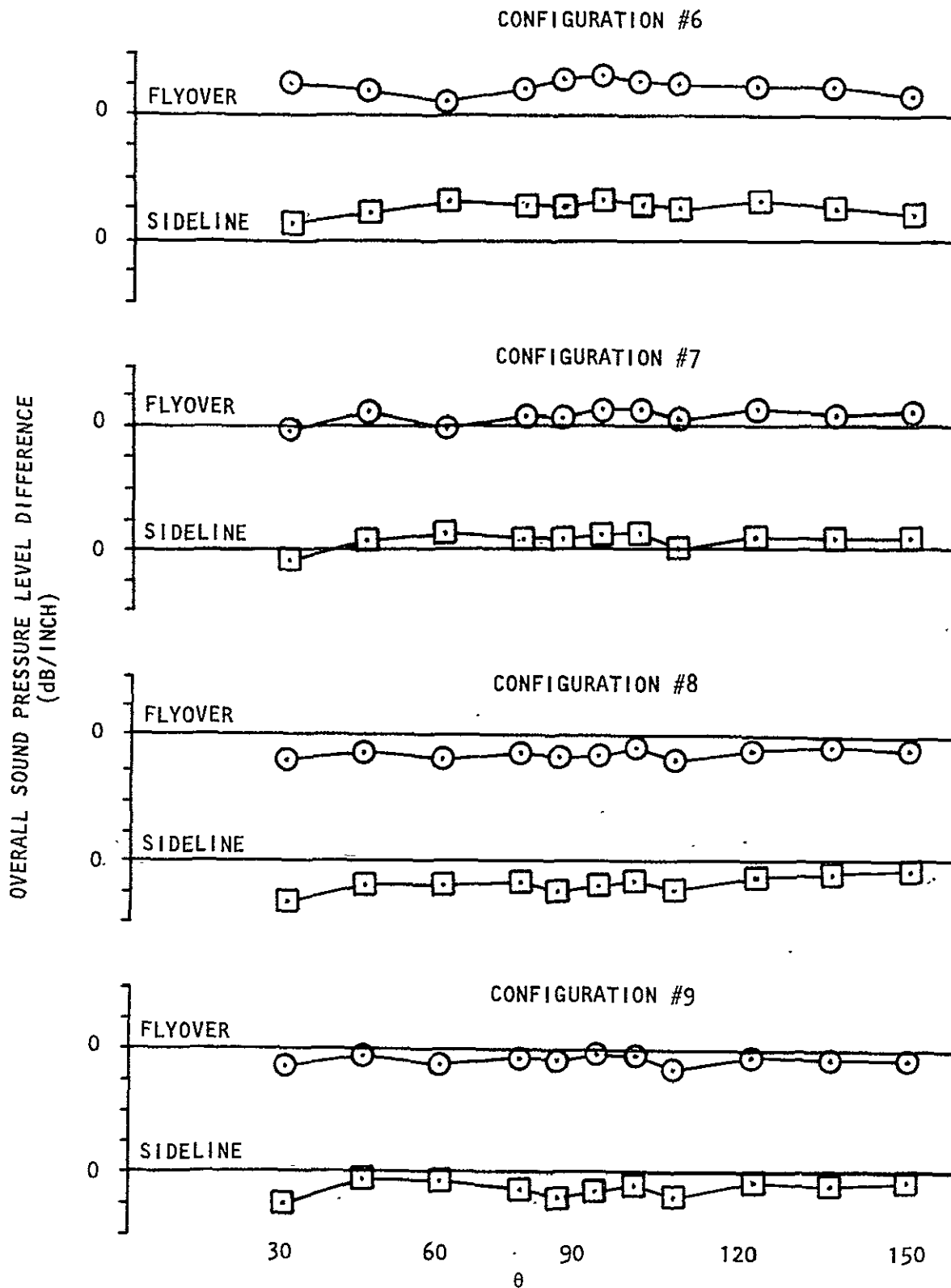
LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



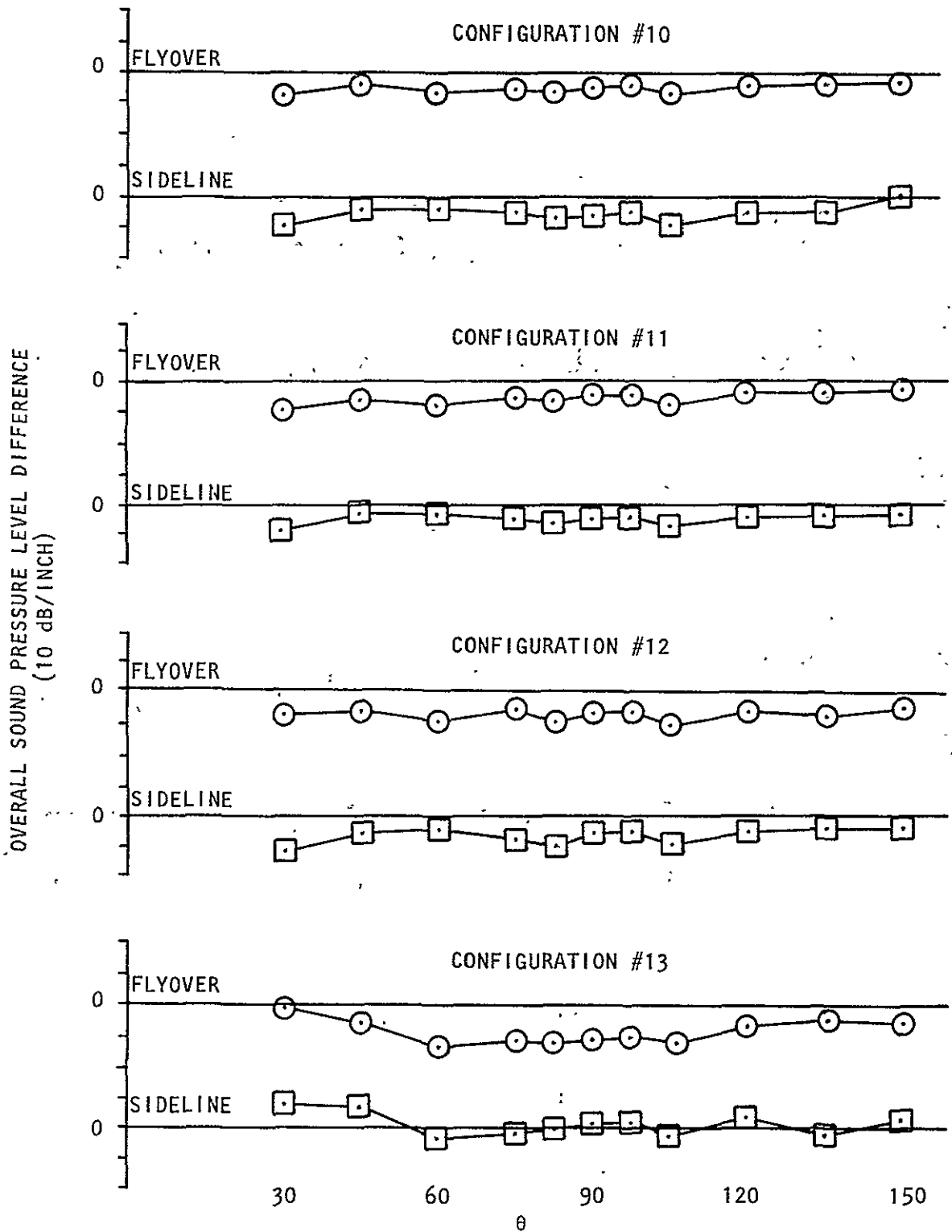
a) CONFIGURATIONS 2 - 5

FIGURE 4-70. CHANGE IN OASPL DUE TO FLAP TREATMENT



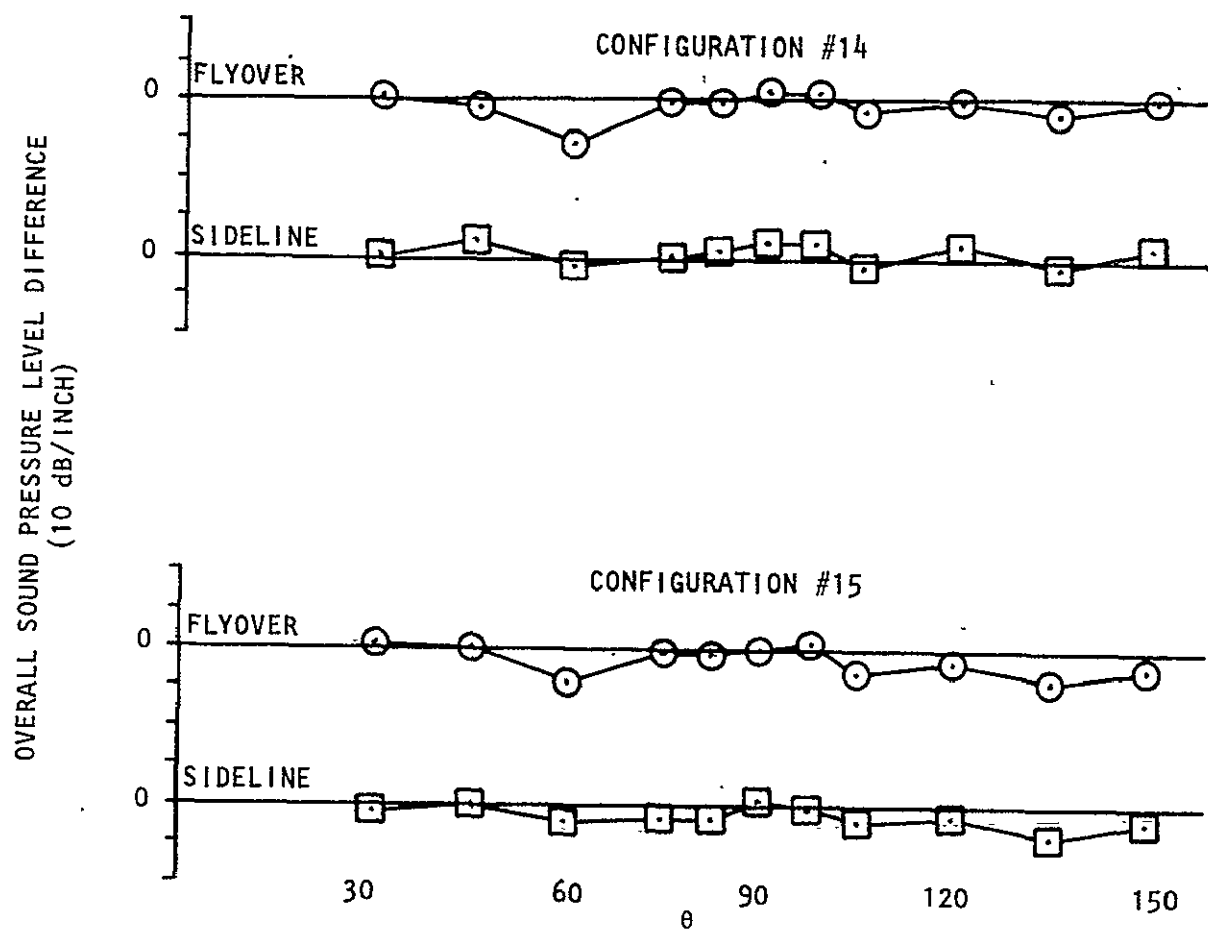
b) CONFIGURATIONS 6 - 9

FIGURE 4-70. (CONTINUED)



c) CONFIGURATIONS 10-13

FIGURE 4-70. (CONTINUED)



d) CONFIGURATIONS 14 AND 15

FIGURE 4-70. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

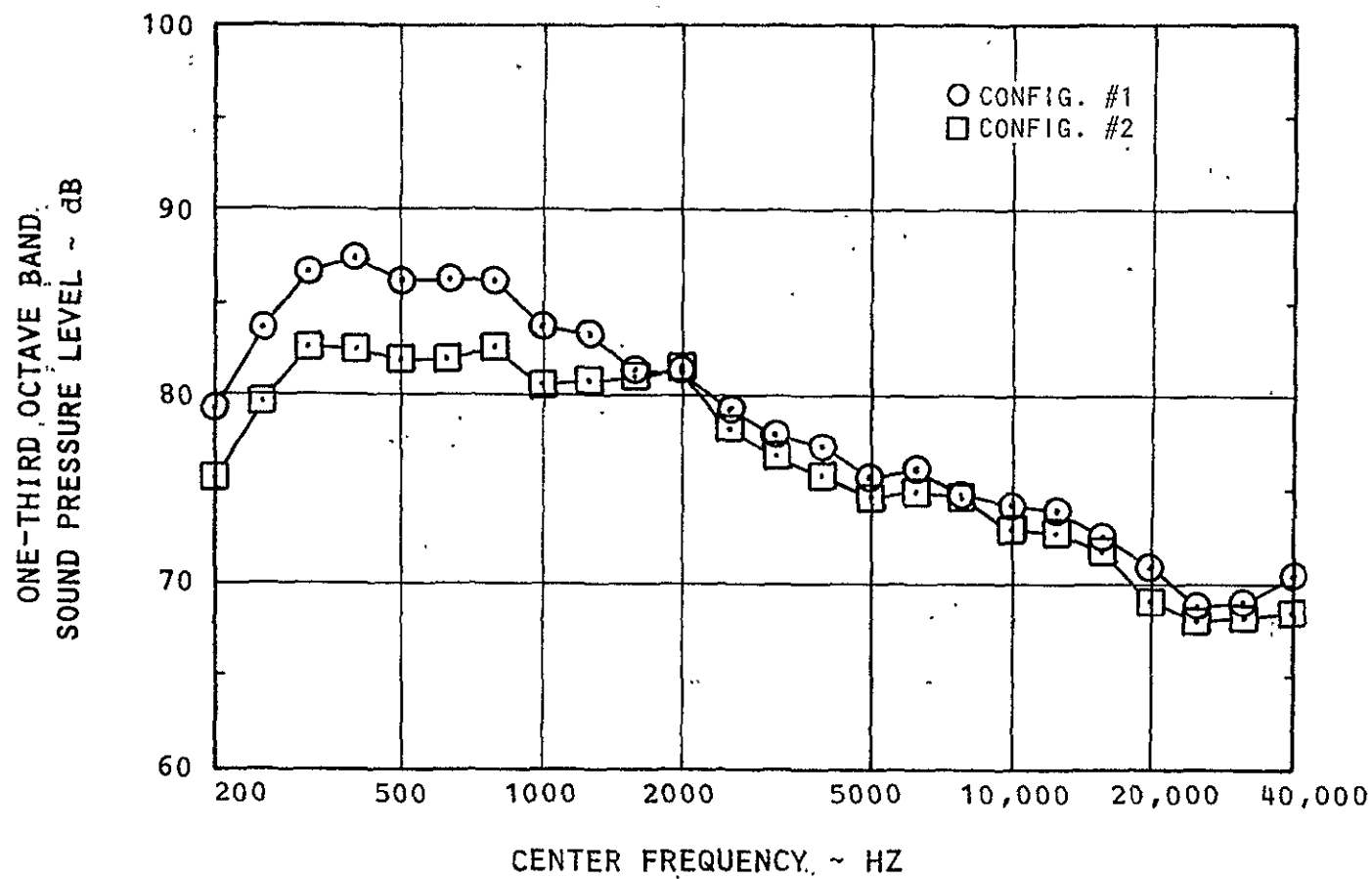
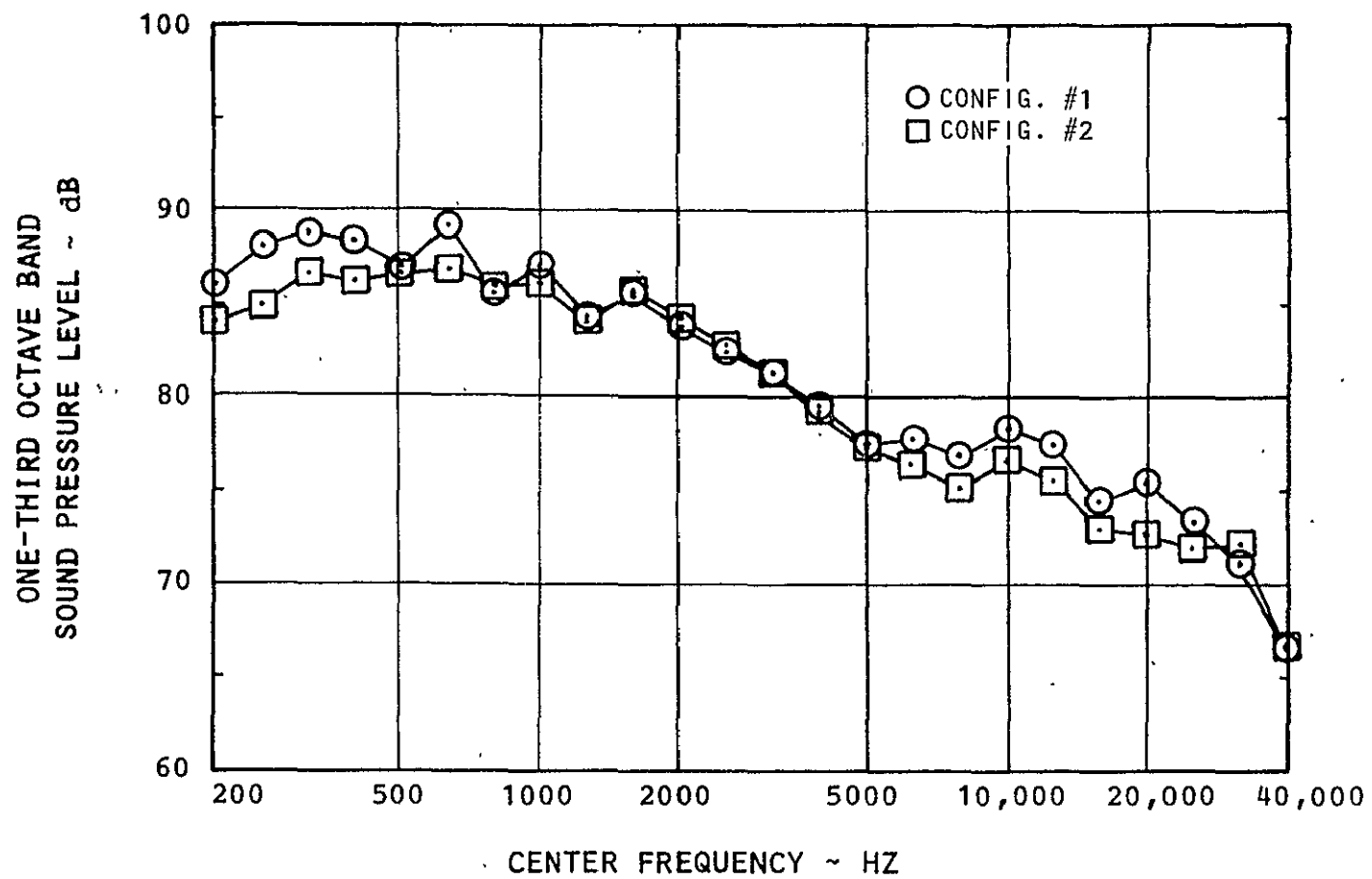
a) $\theta = 60^\circ$

FIGURE 4-71. EFFECT OF NOISE REDUCTION CONFIGURATION 2

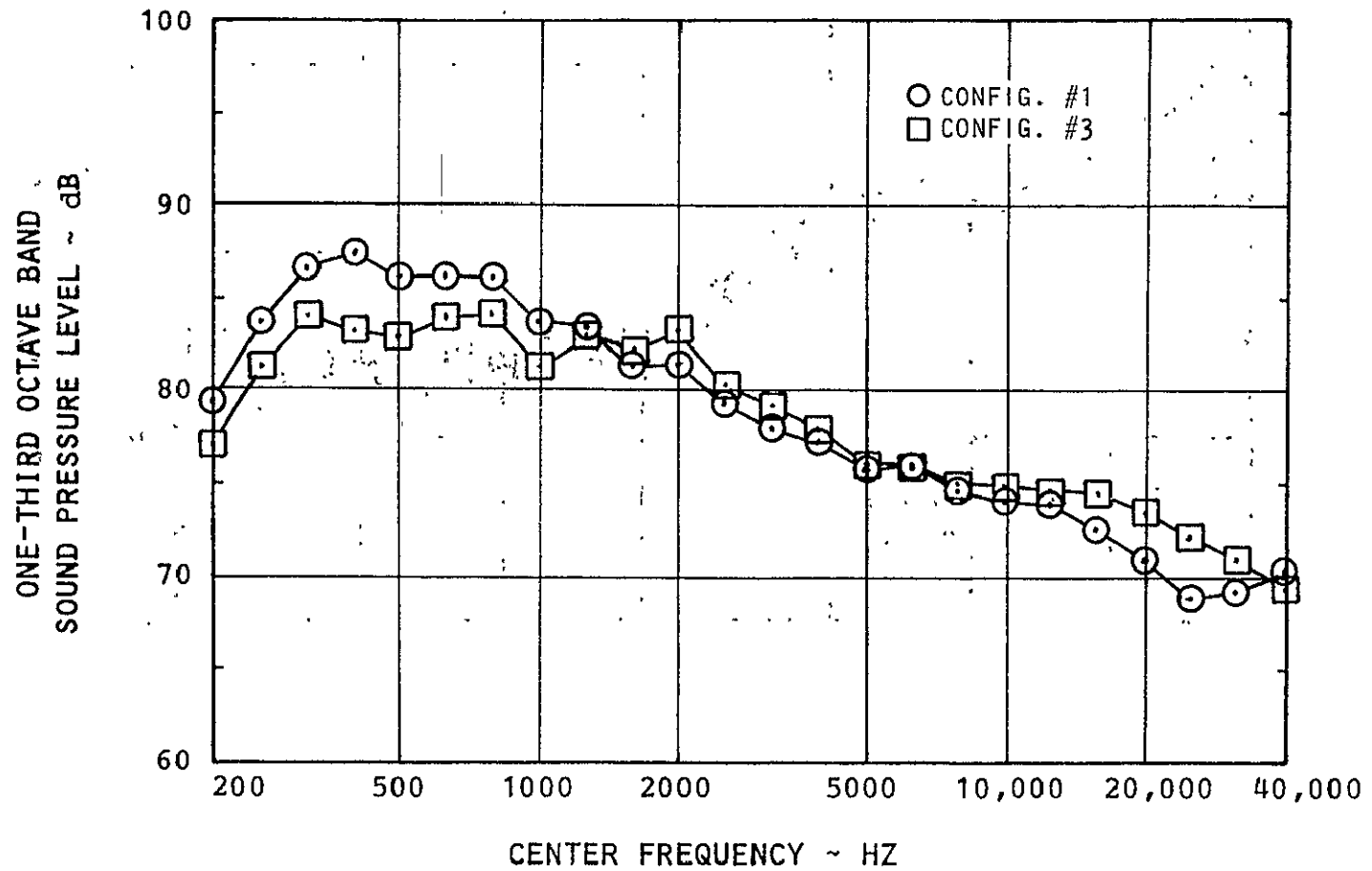
LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-71. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-72. EFFECT OF NOISE REDUCTION CONFIGURATION 3

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

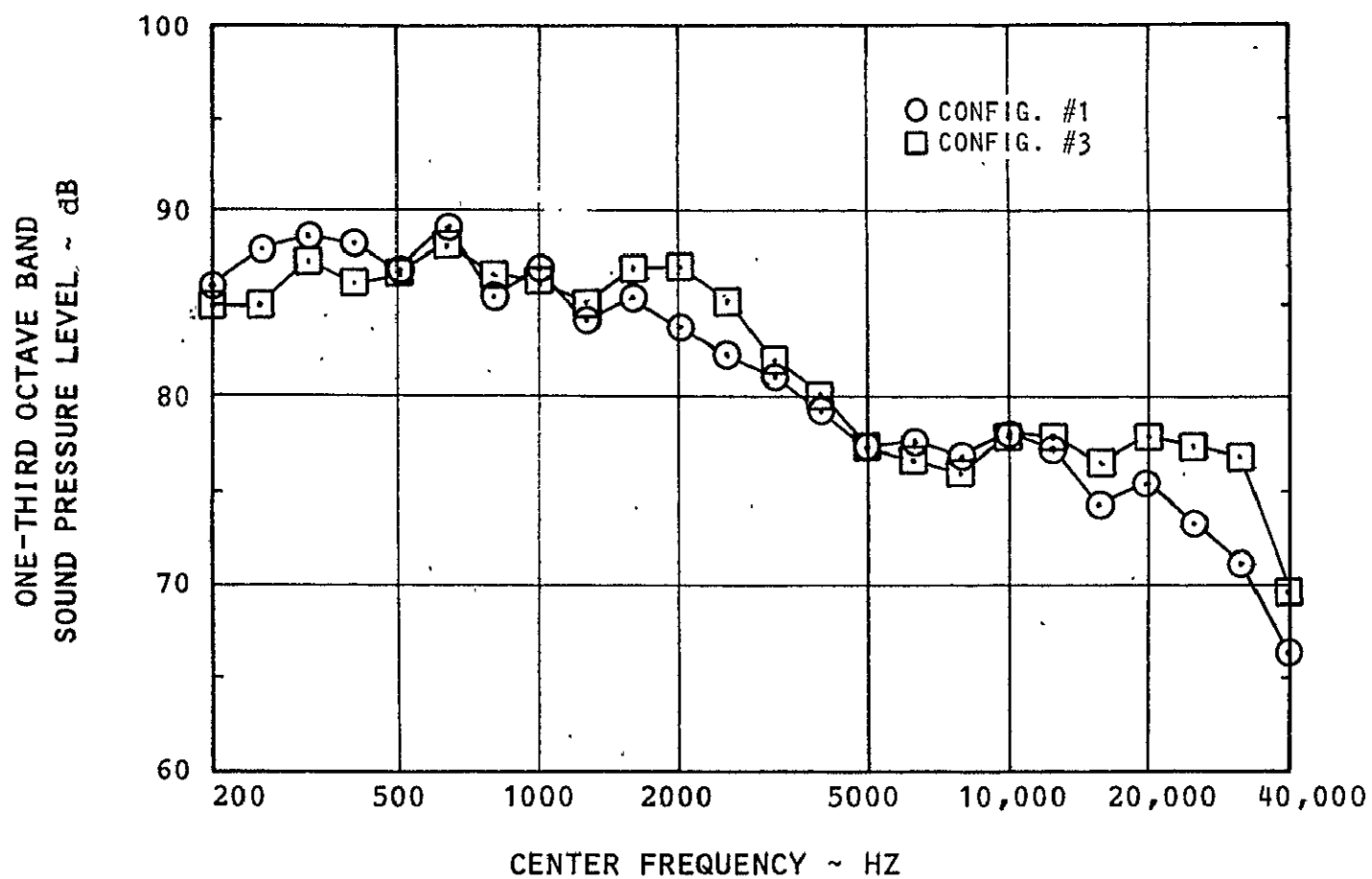
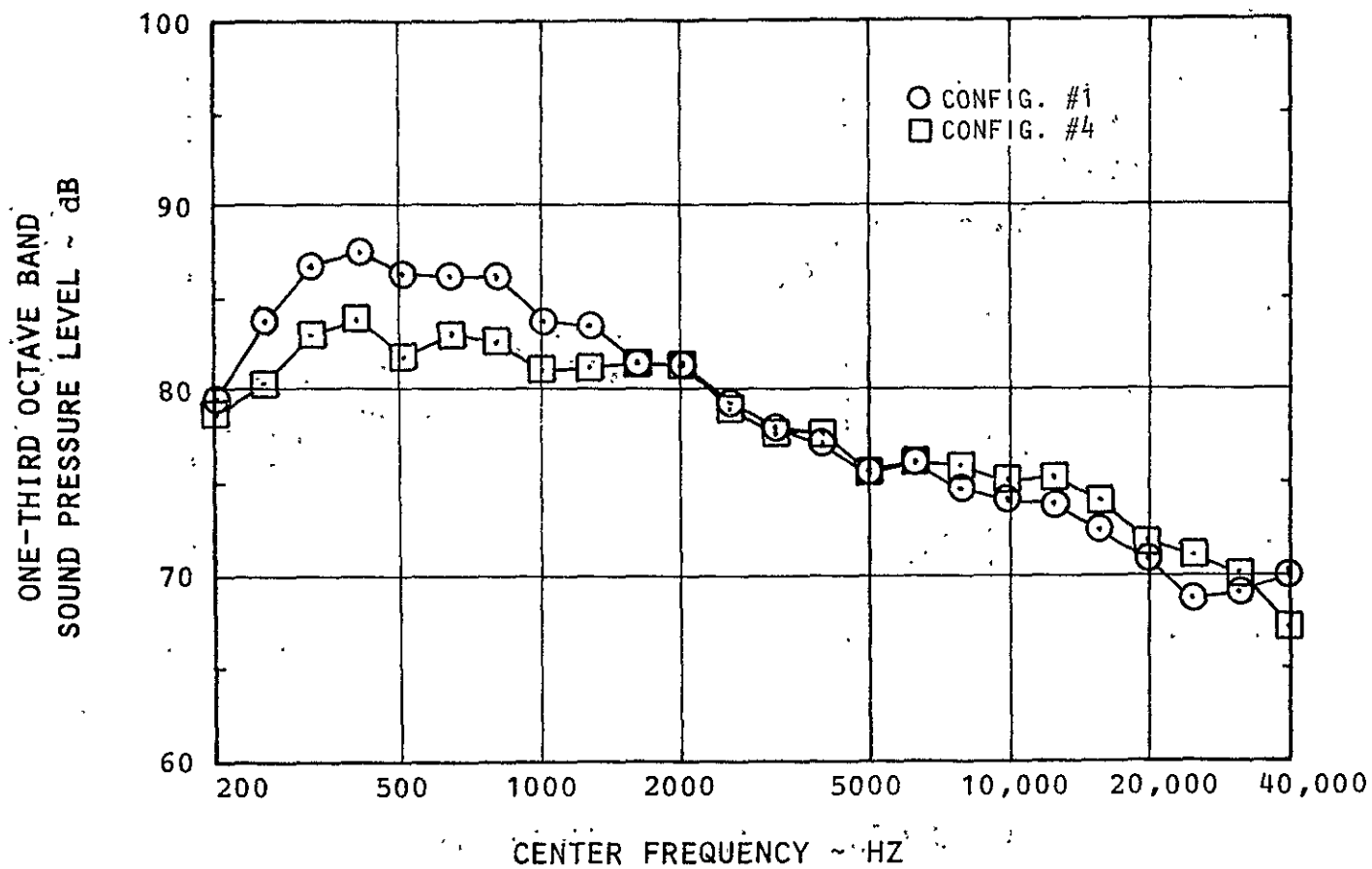
b) $\theta = 120^\circ$

FIGURE 4-72. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

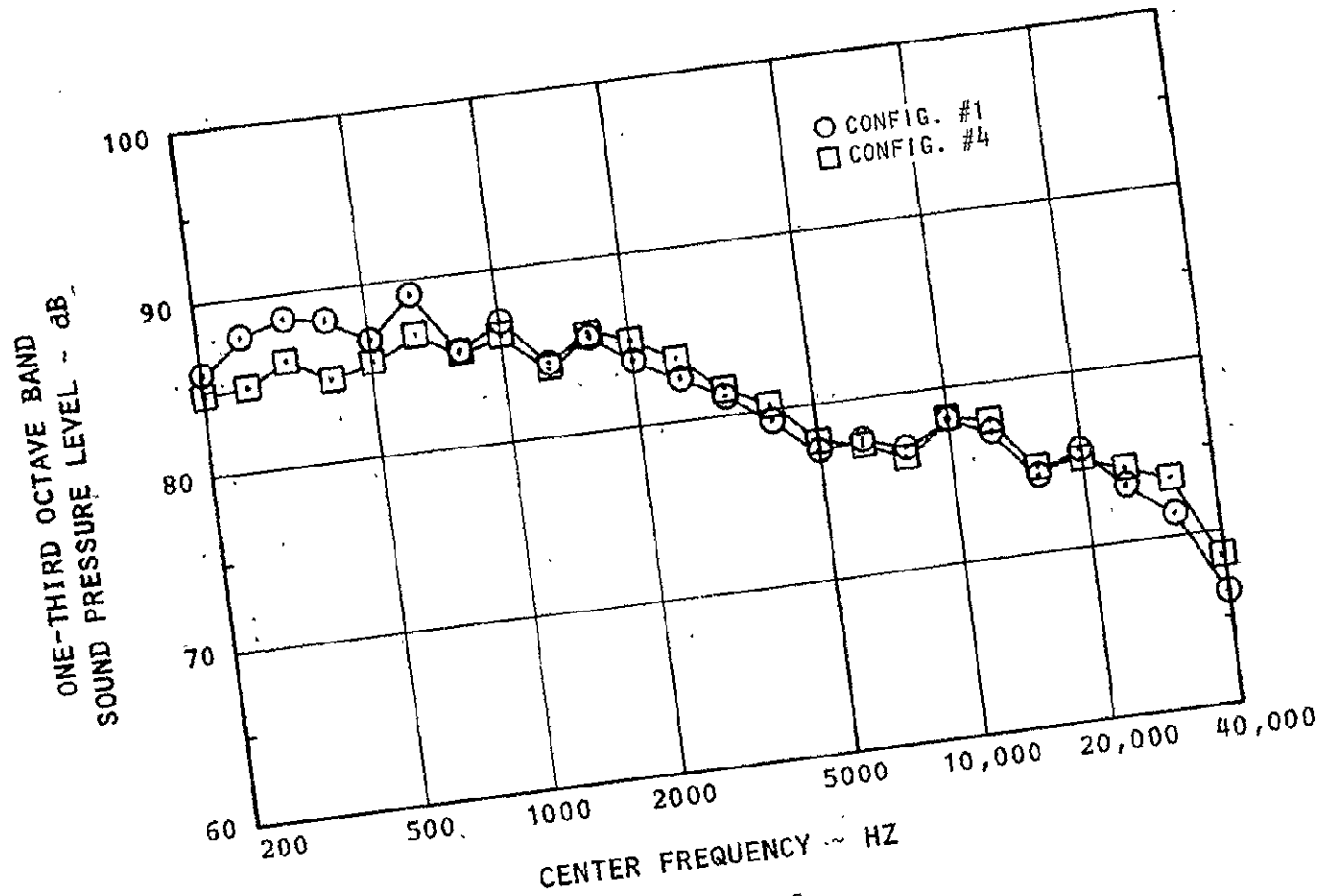
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-73. EFFECT OF NOISE REDUCTION CONFIGURATION 4

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

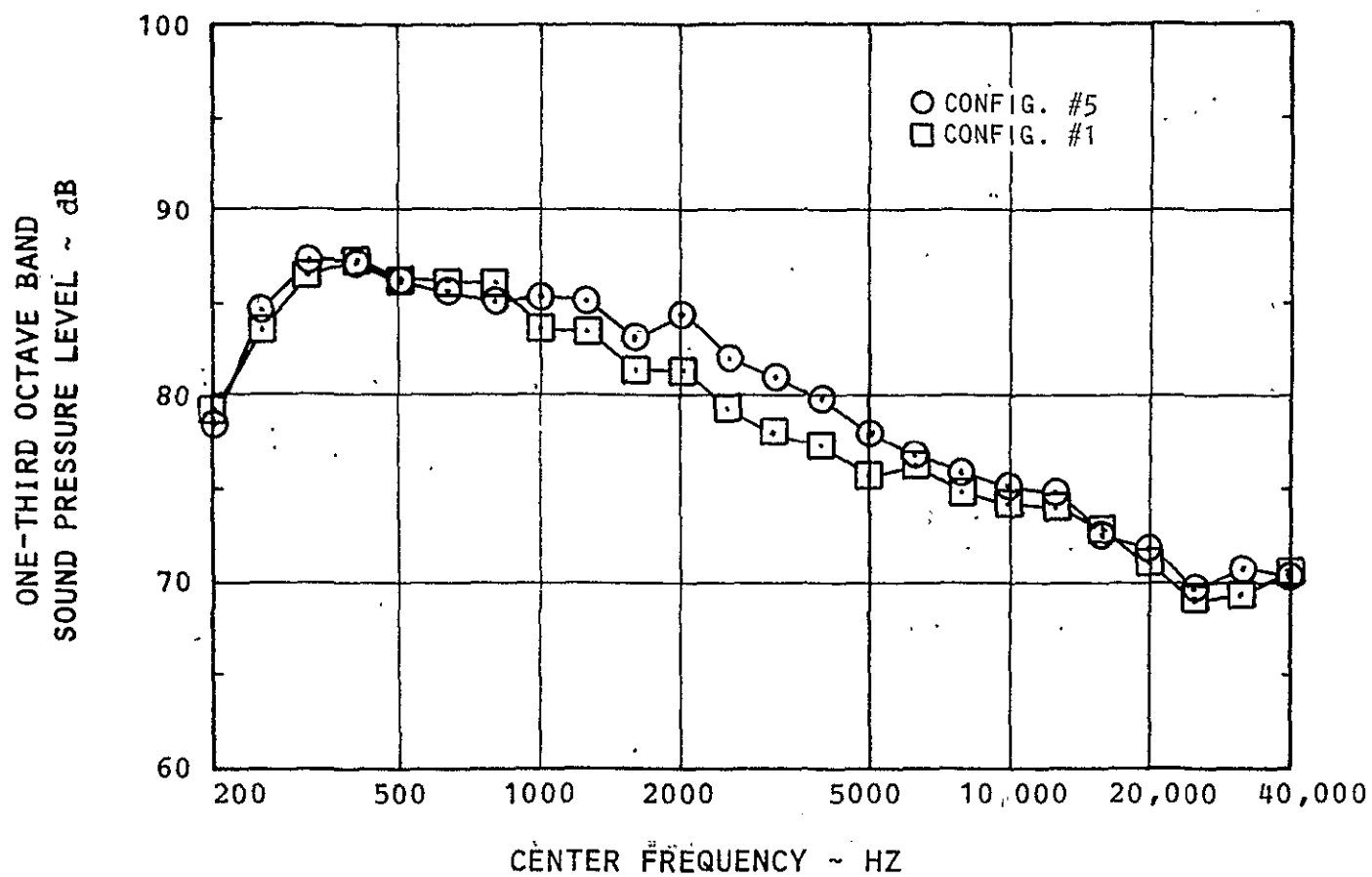


b) $\theta = 120^\circ$

FIGURE 4-73. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-74. EFFECT OF NOISE REDUCTION CONFIGURATION 5

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

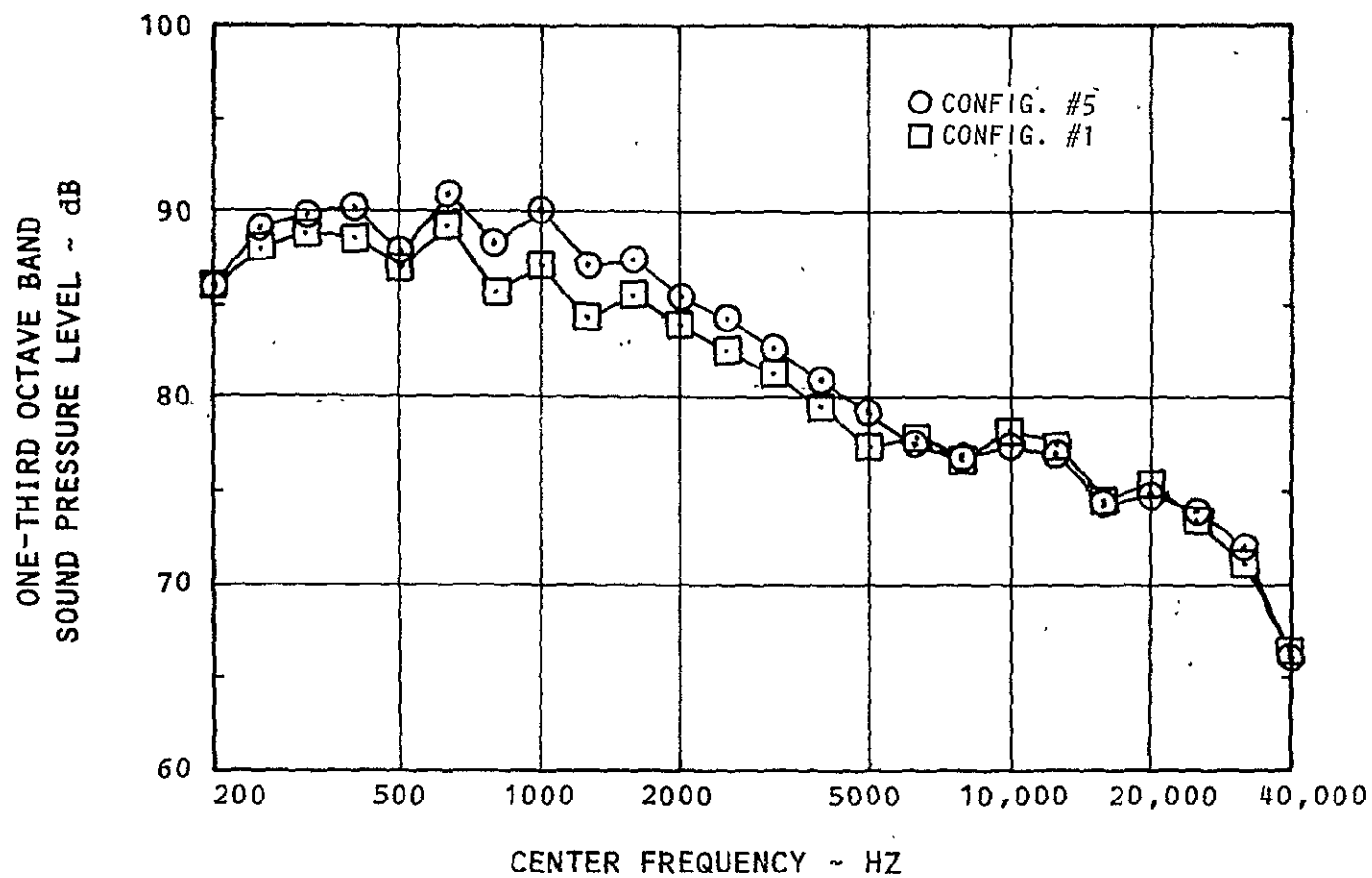
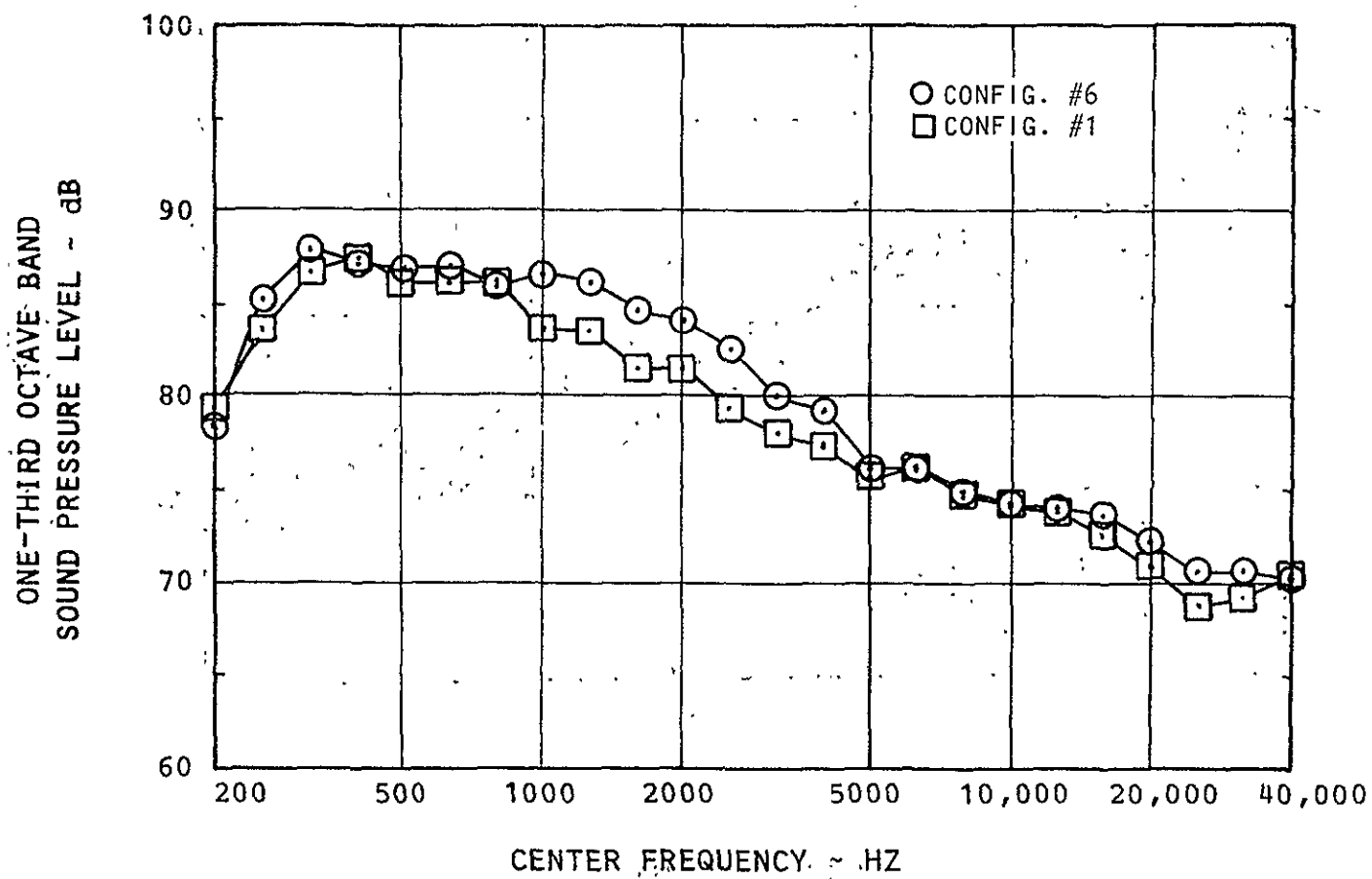
b) $\theta = 120^\circ$

FIGURE 4-74. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

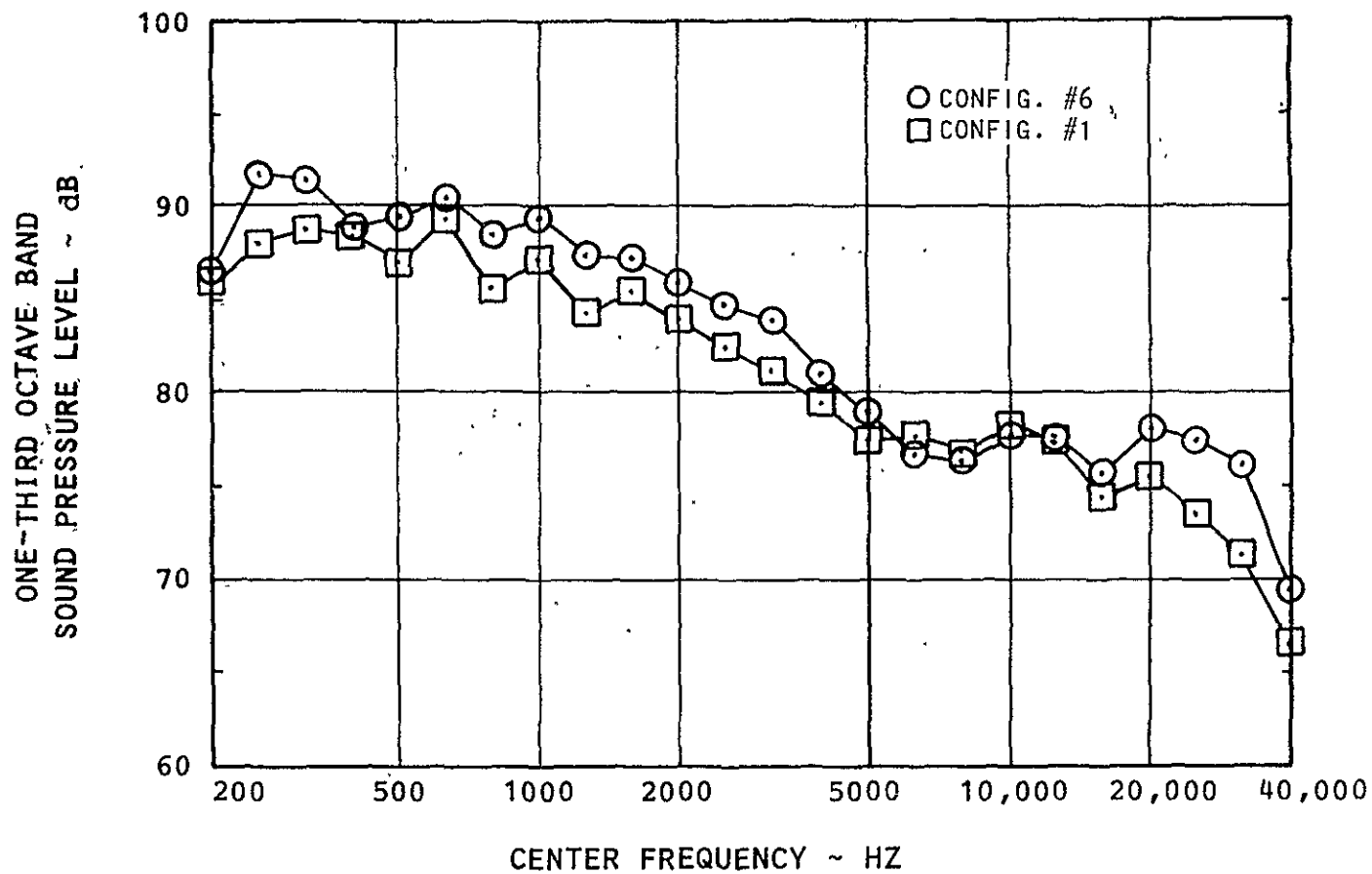
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-75. EFFECT OF NOISE REDUCTION CONFIGURATION 6

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

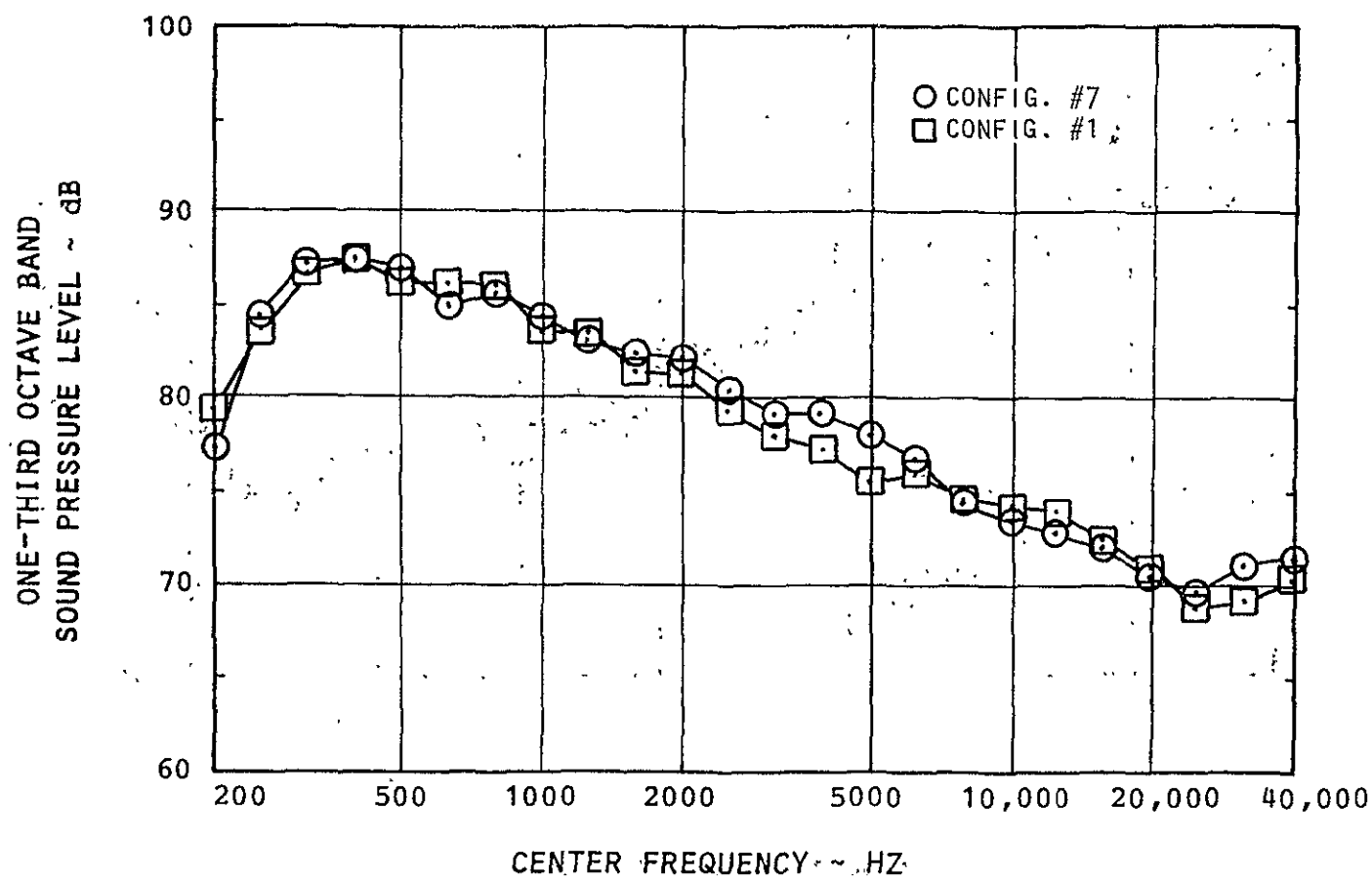


b) $\theta = 120^\circ$

FIGURE 4-75. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-76. EFFECT OF NOISE REDUCTION CONFIGURATION 7

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

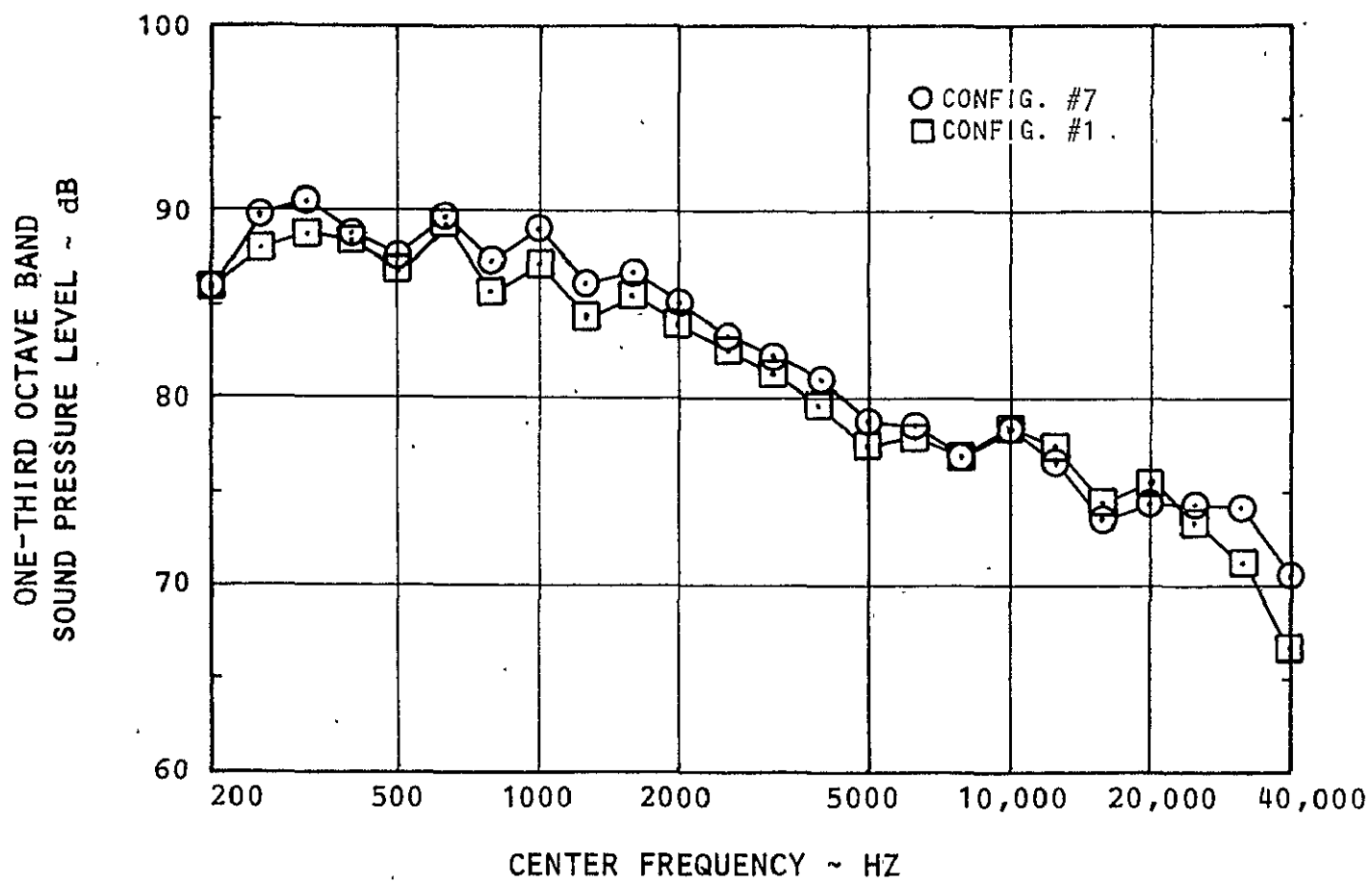
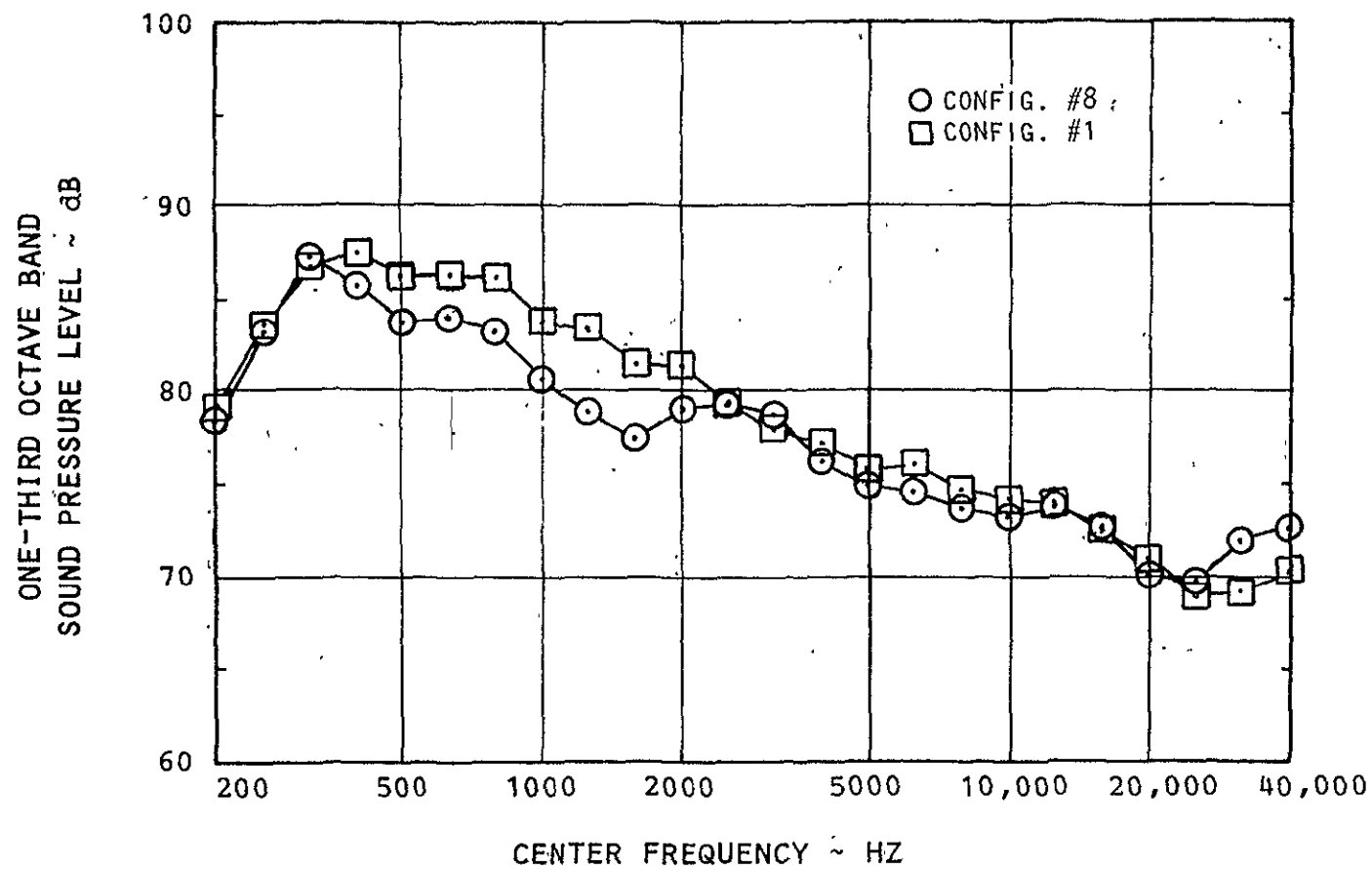
b) $\theta = 120^\circ$

FIGURE 4-76. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

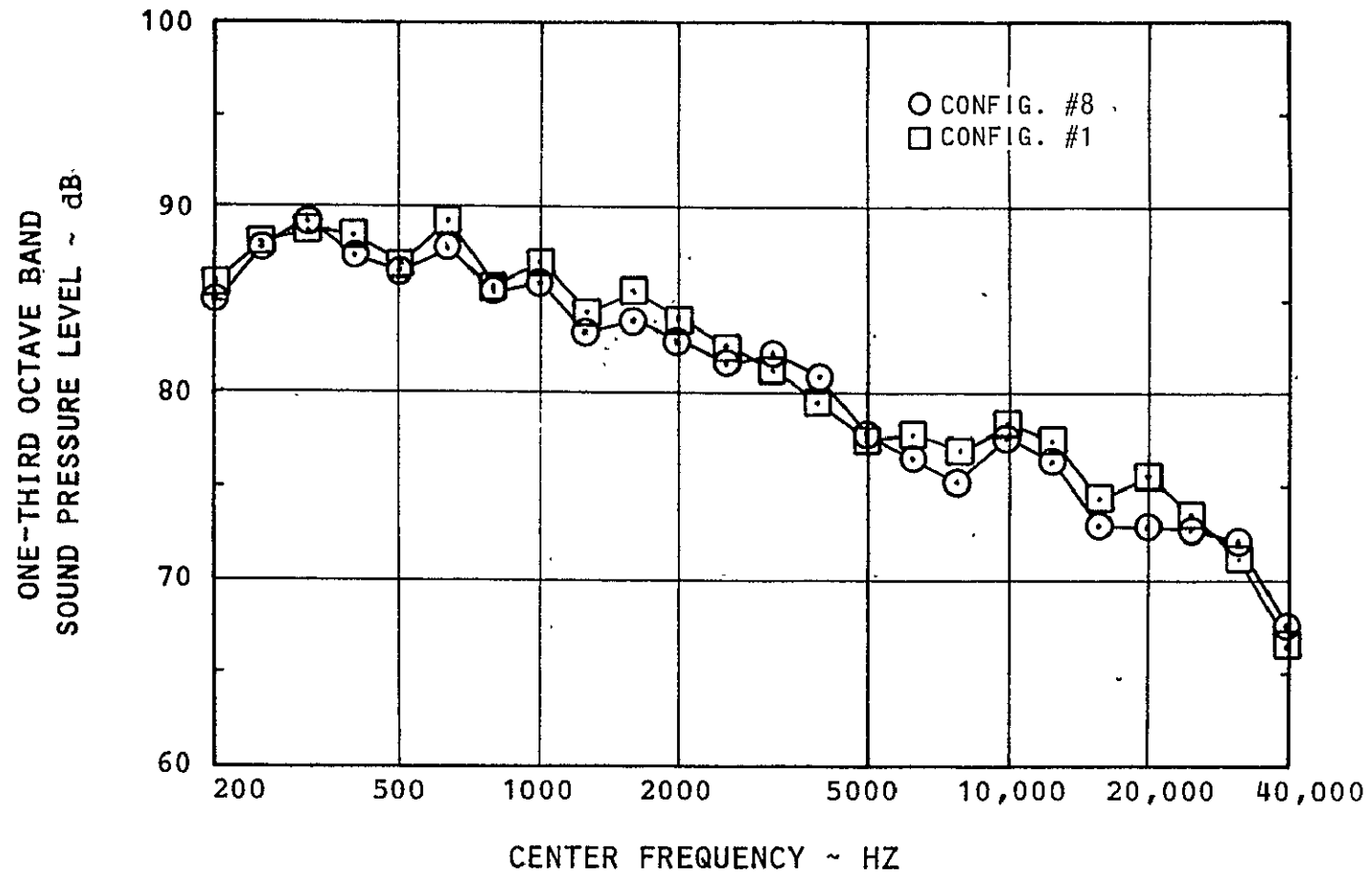
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-77. EFFECT OF NOISE REDUCTION CONFIGURATION 8

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

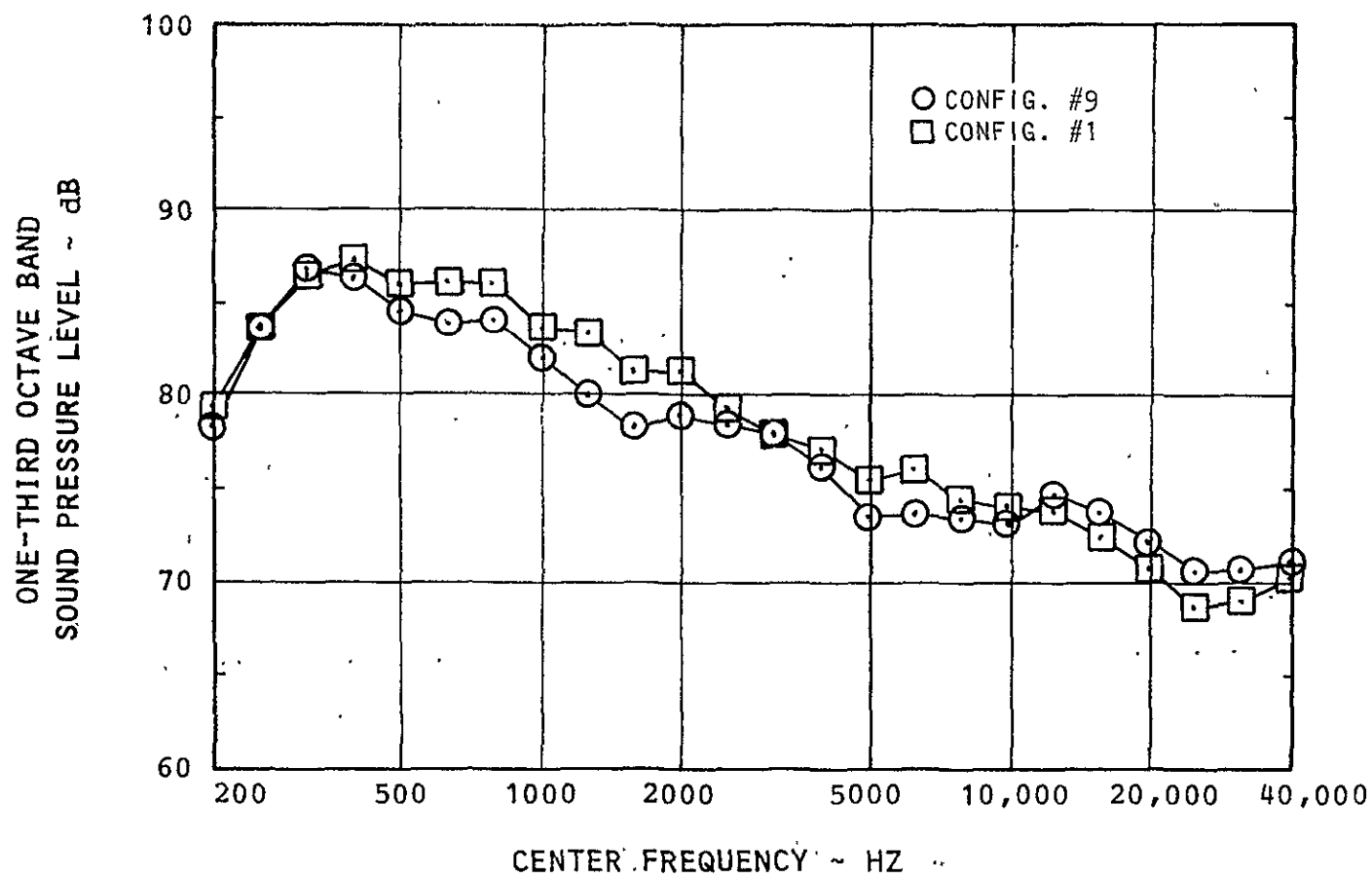


b) $\theta = 120^\circ$

FIGURE 4-77. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

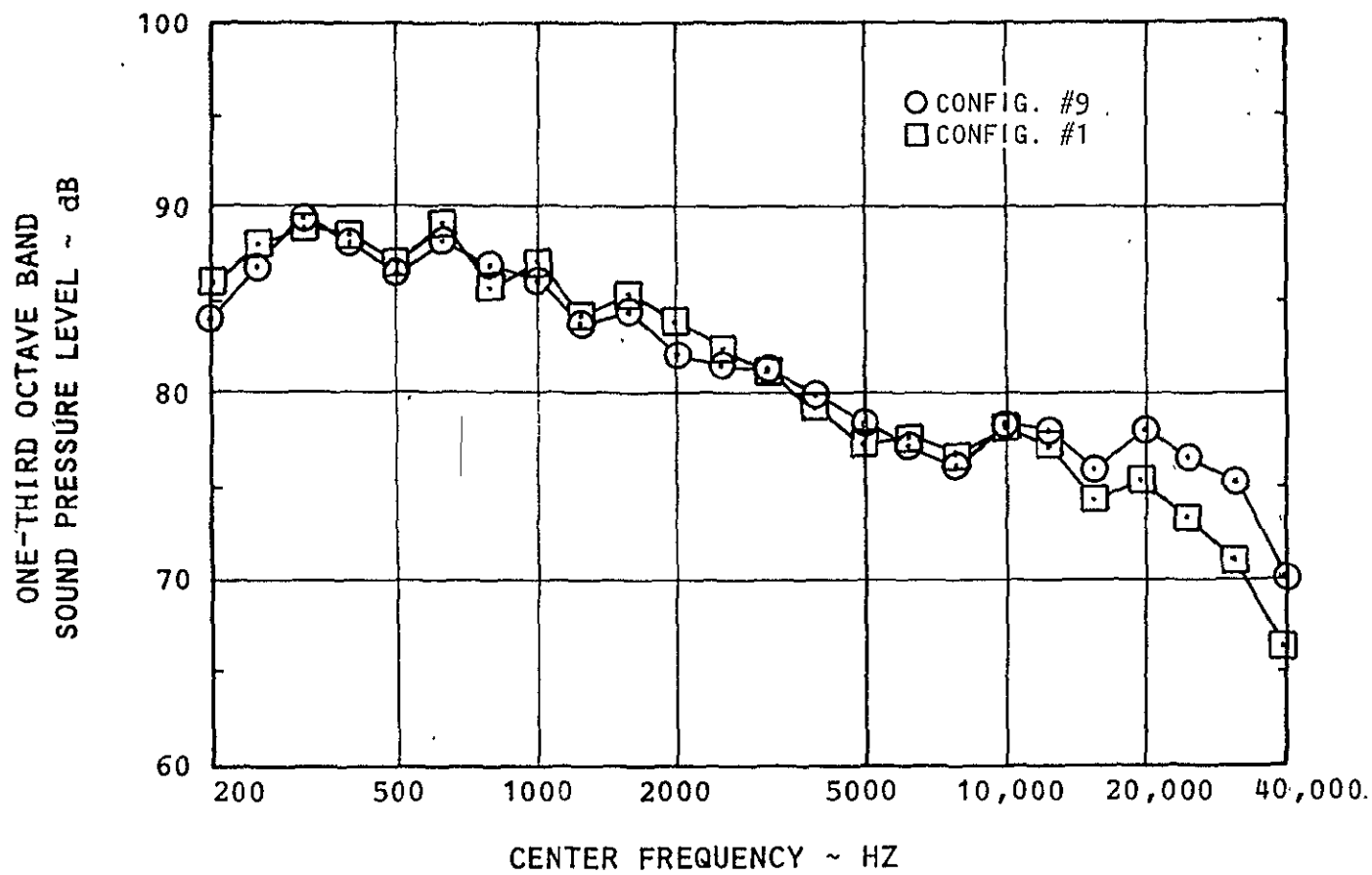
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta \approx 60^\circ$

FIGURE 4-78. EFFECT OF NOISE REDUCTION CONFIGURATION 9

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-78. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

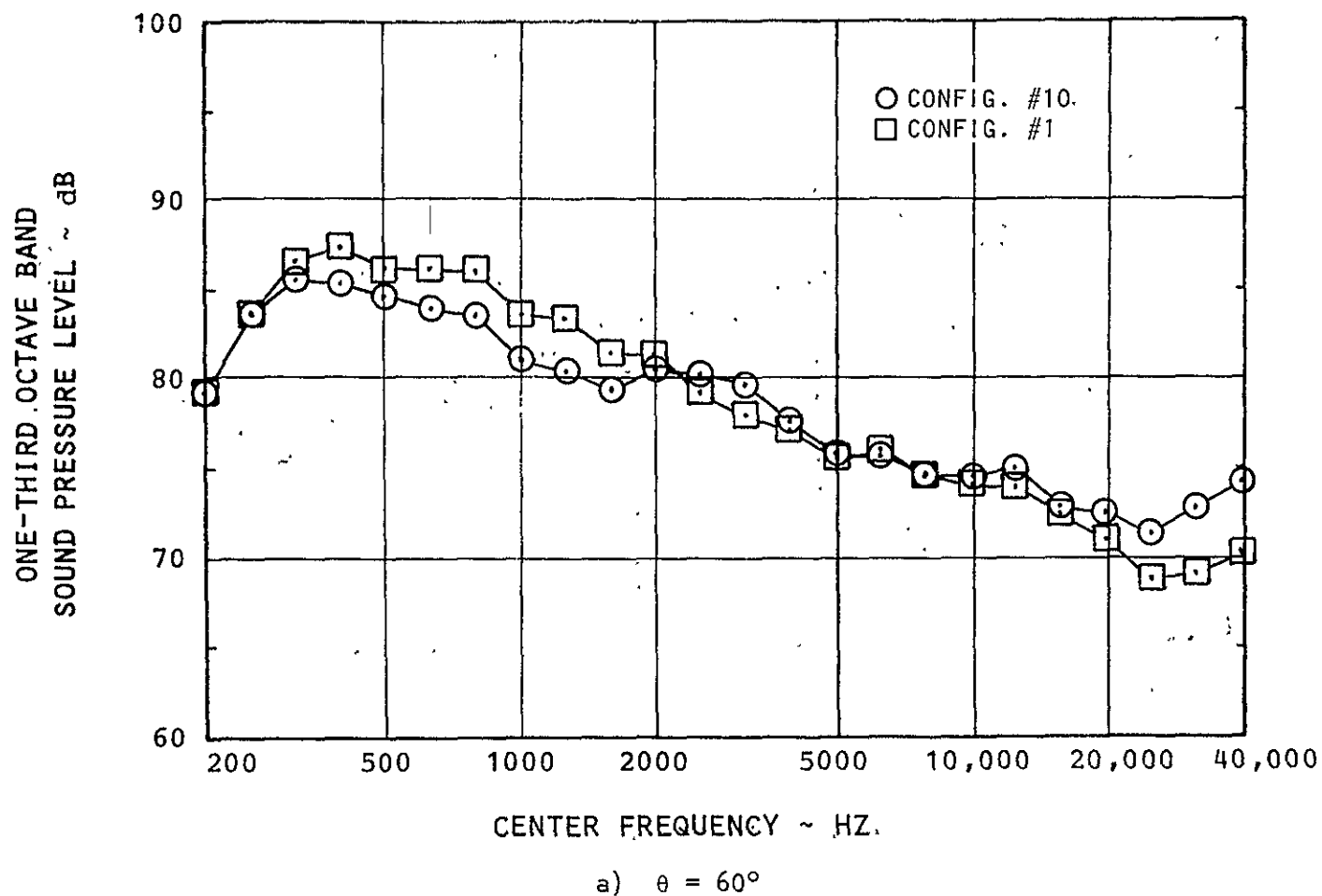


FIGURE 4-79. EFFECT OF NOISE REDUCTION CONFIGURATION 10

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

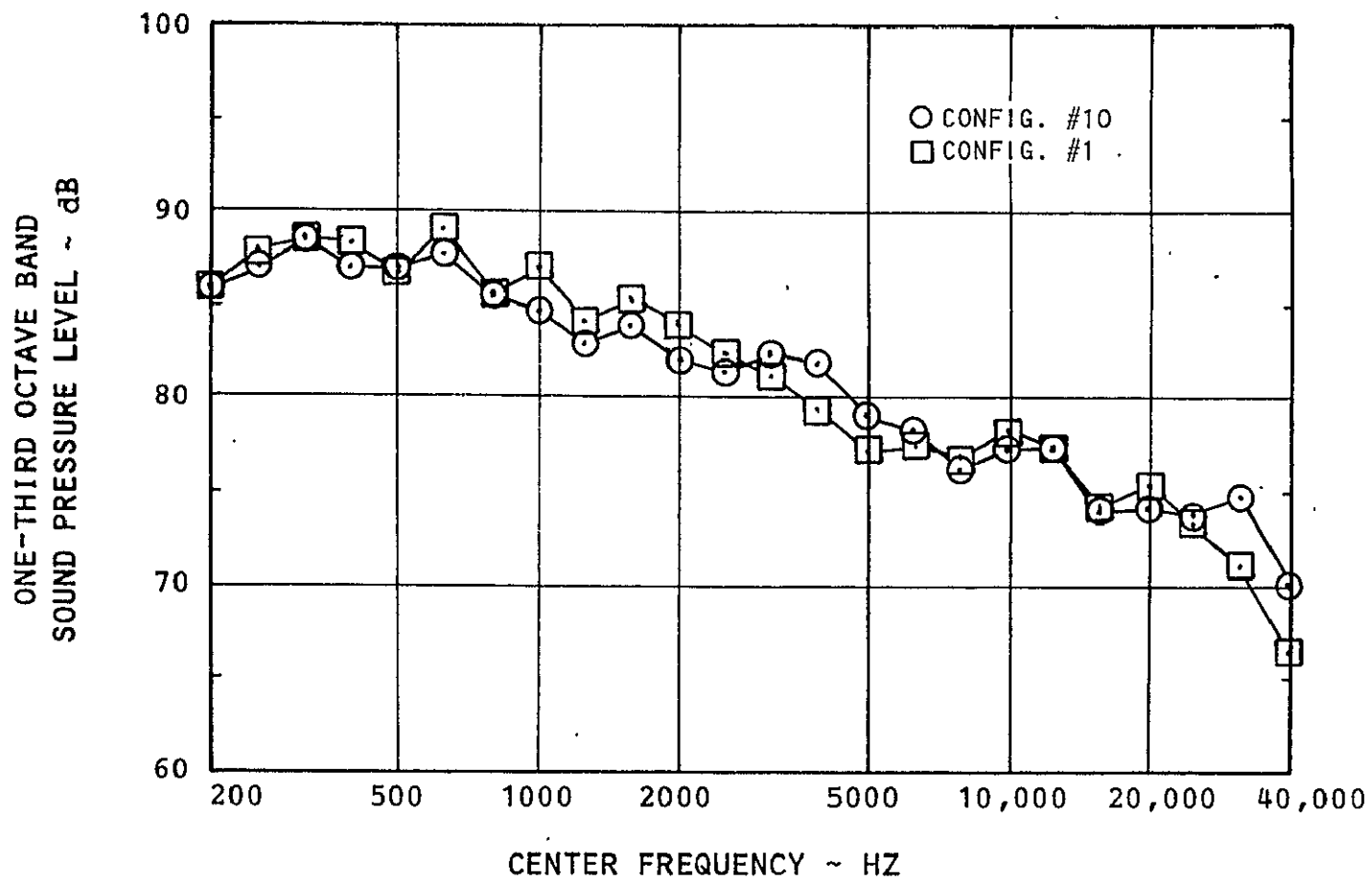
b) $\theta = 120^\circ$

FIGURE 4-79. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

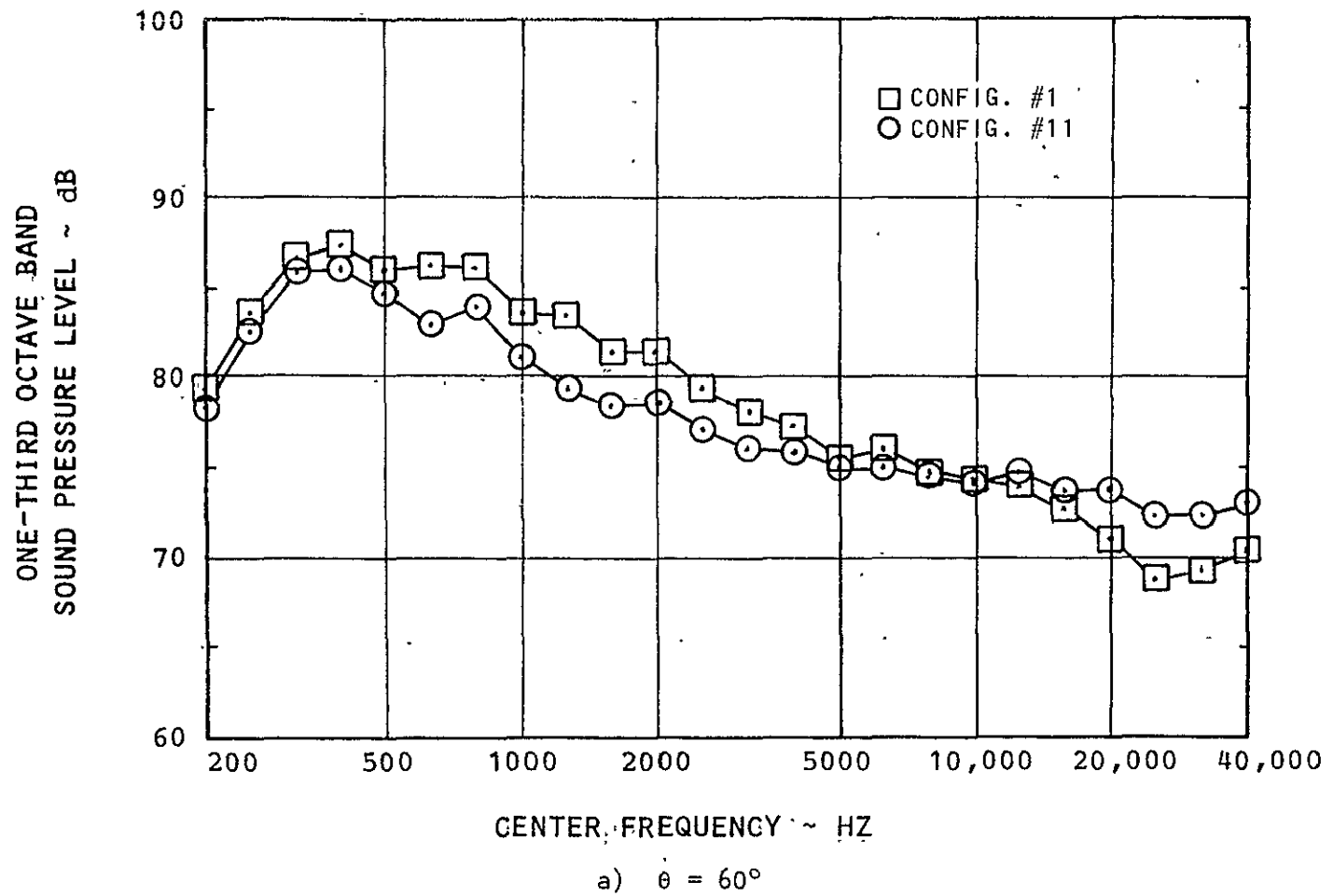
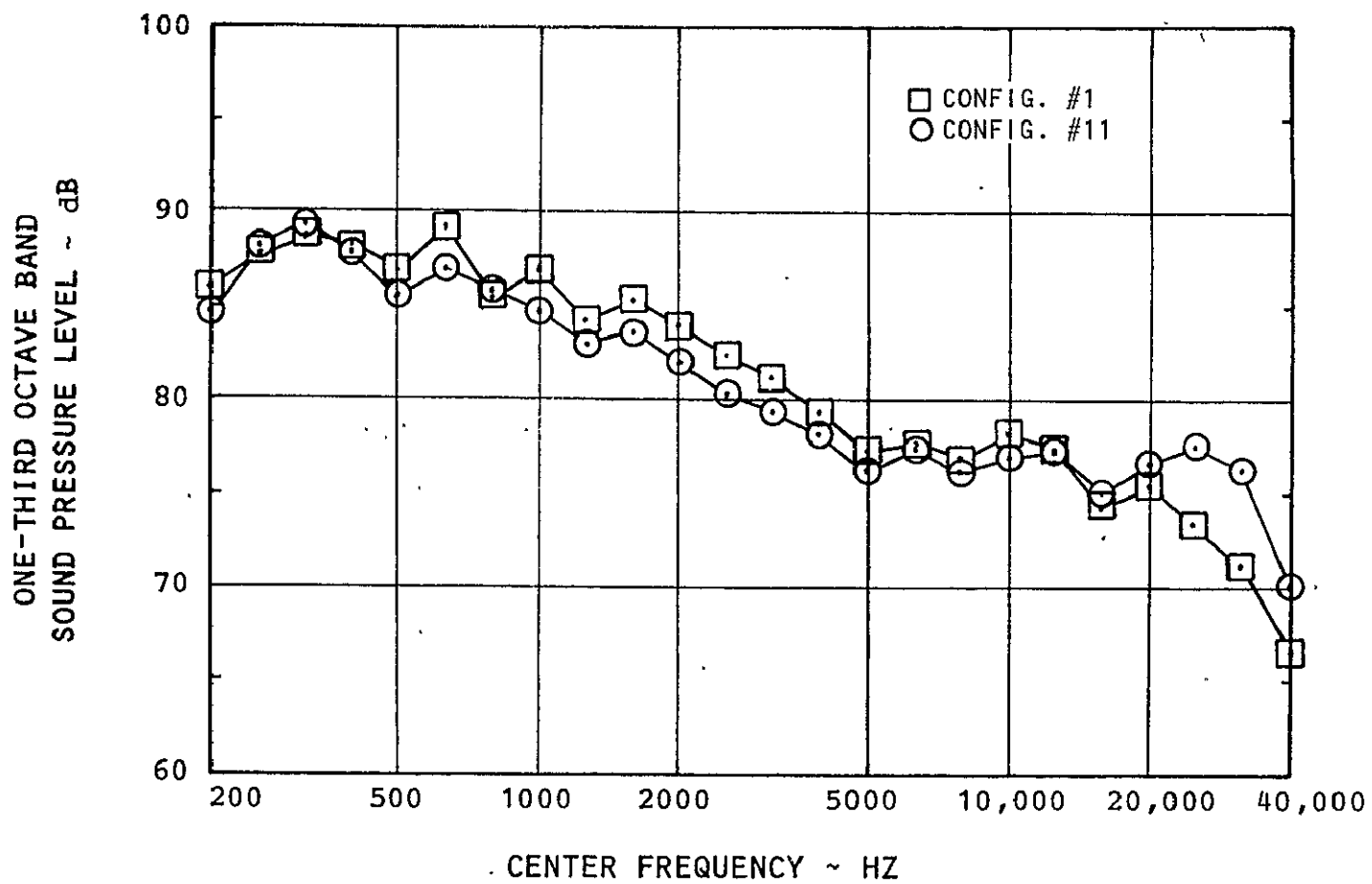


FIGURE 4-80. EFFECT OF NOISE REDUCTION CONFIGURATION 11

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS



b) = 120°

FIGURE 4-80. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

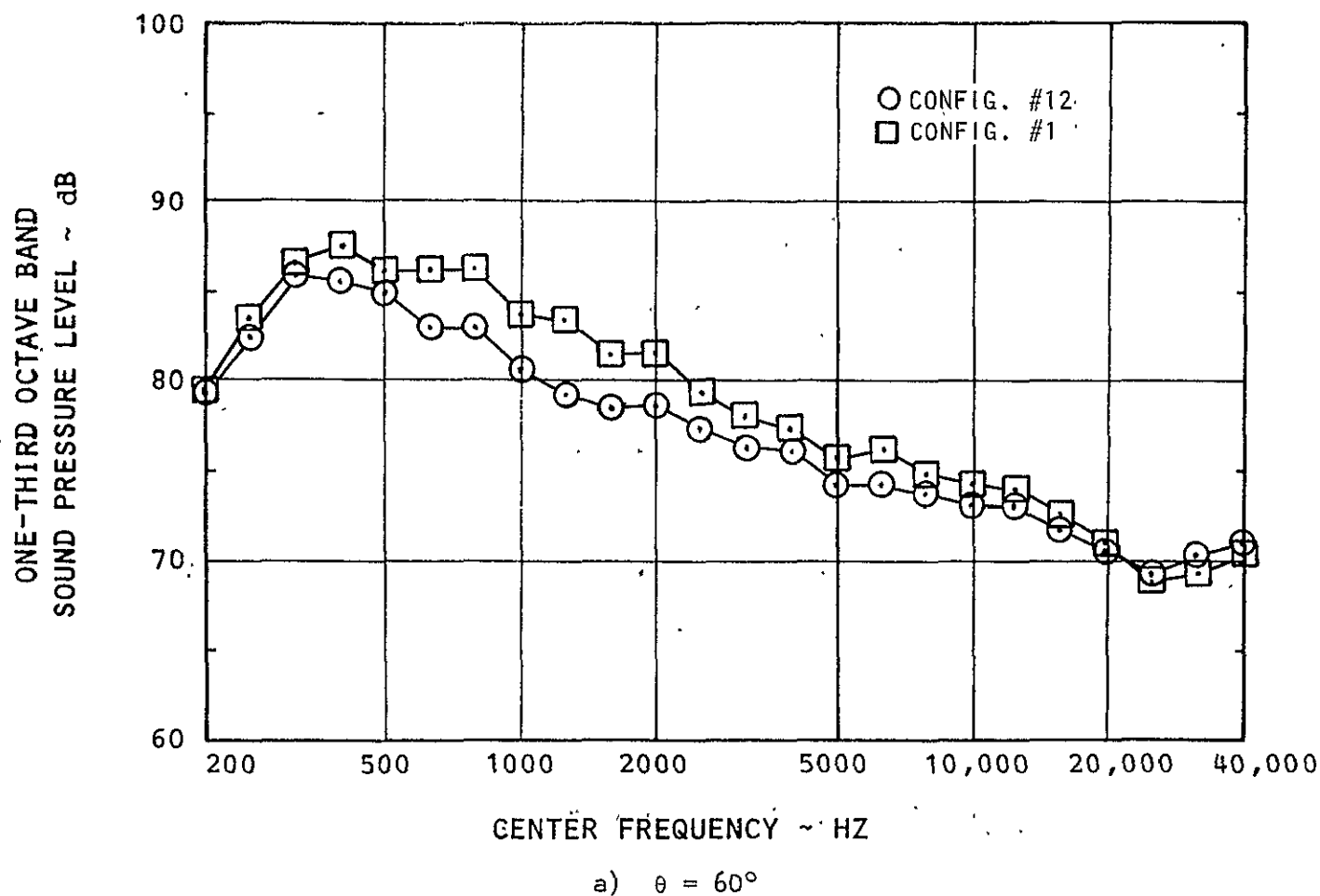


FIGURE 4-81. EFFECT OF NOISE REDUCTION CONFIGURATION 12

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

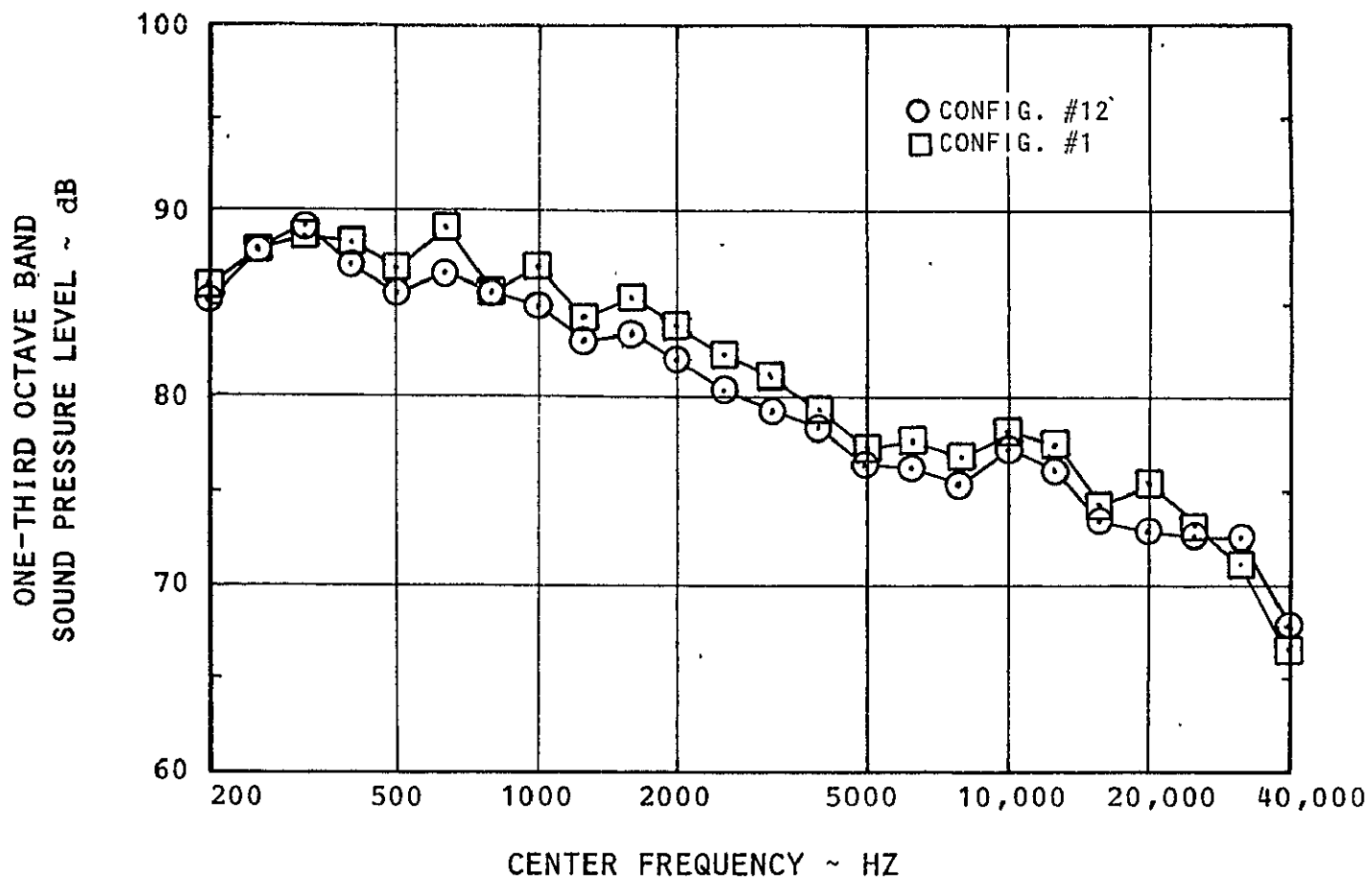
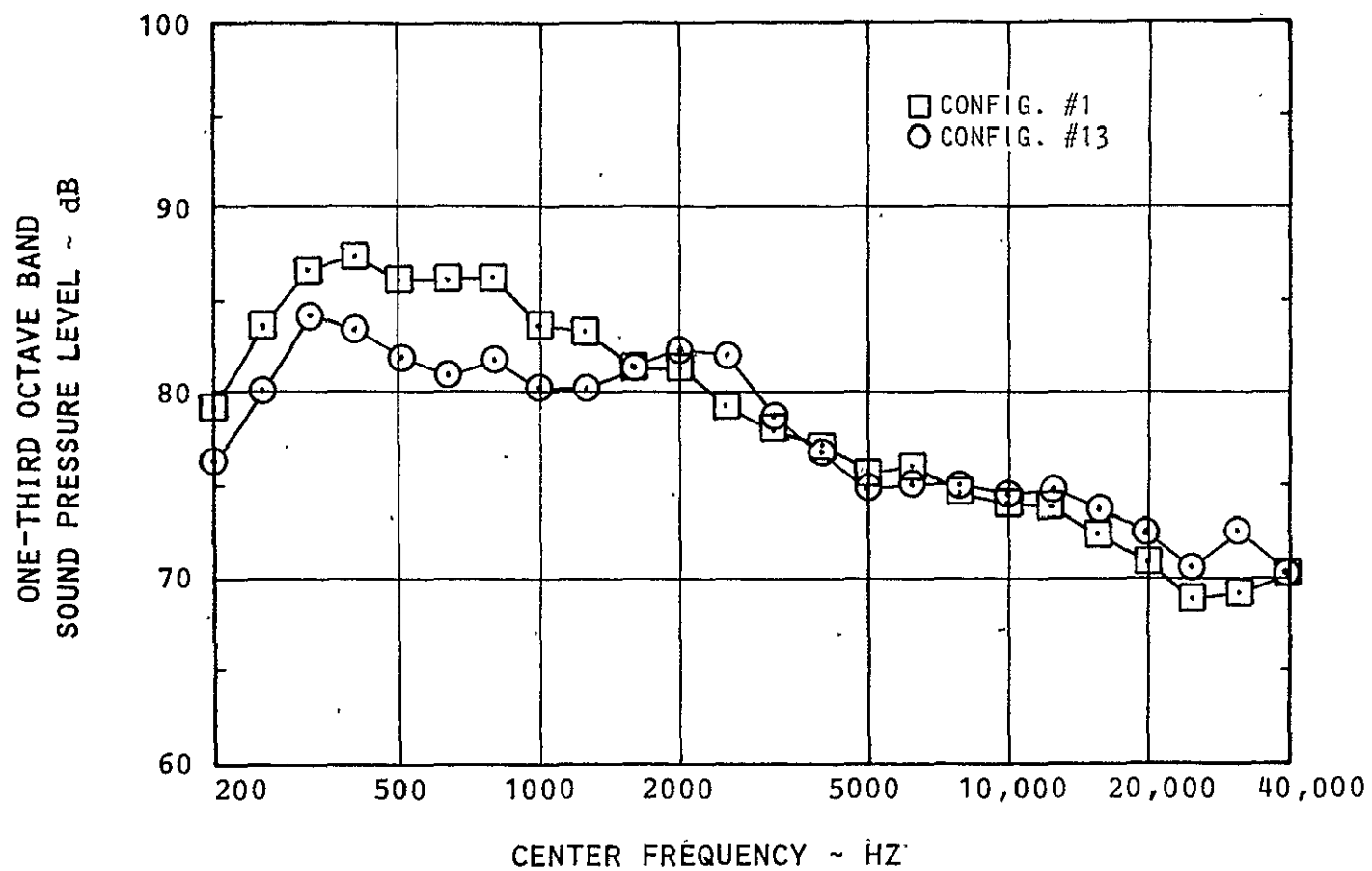
b) $\theta = 120^\circ$

FIGURE 4-81. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-82. EFFECT OF NOISE REDUCTION CONFIGURATION 13

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

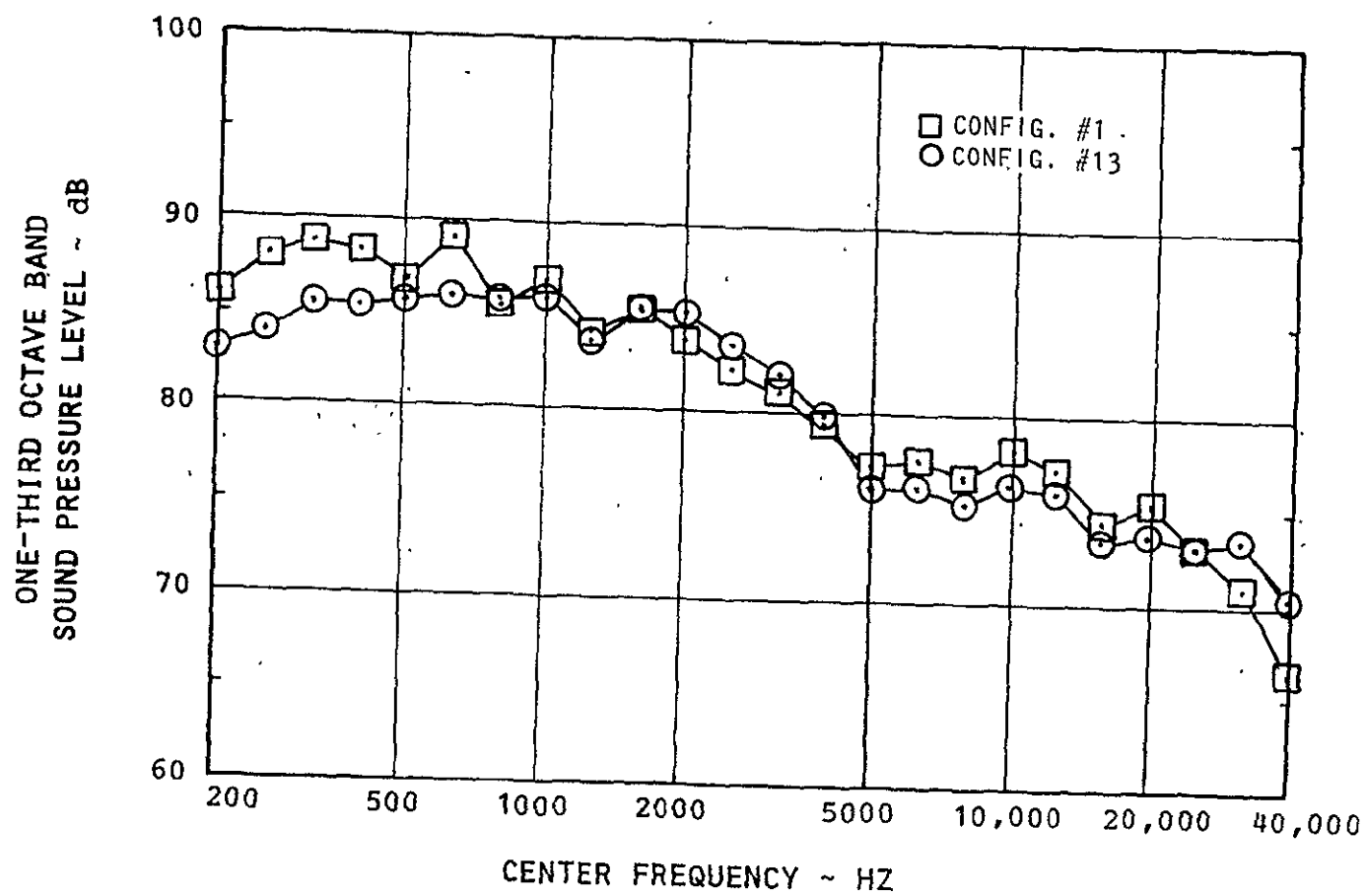
b) $\theta = 120^\circ$

FIGURE 4-82. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

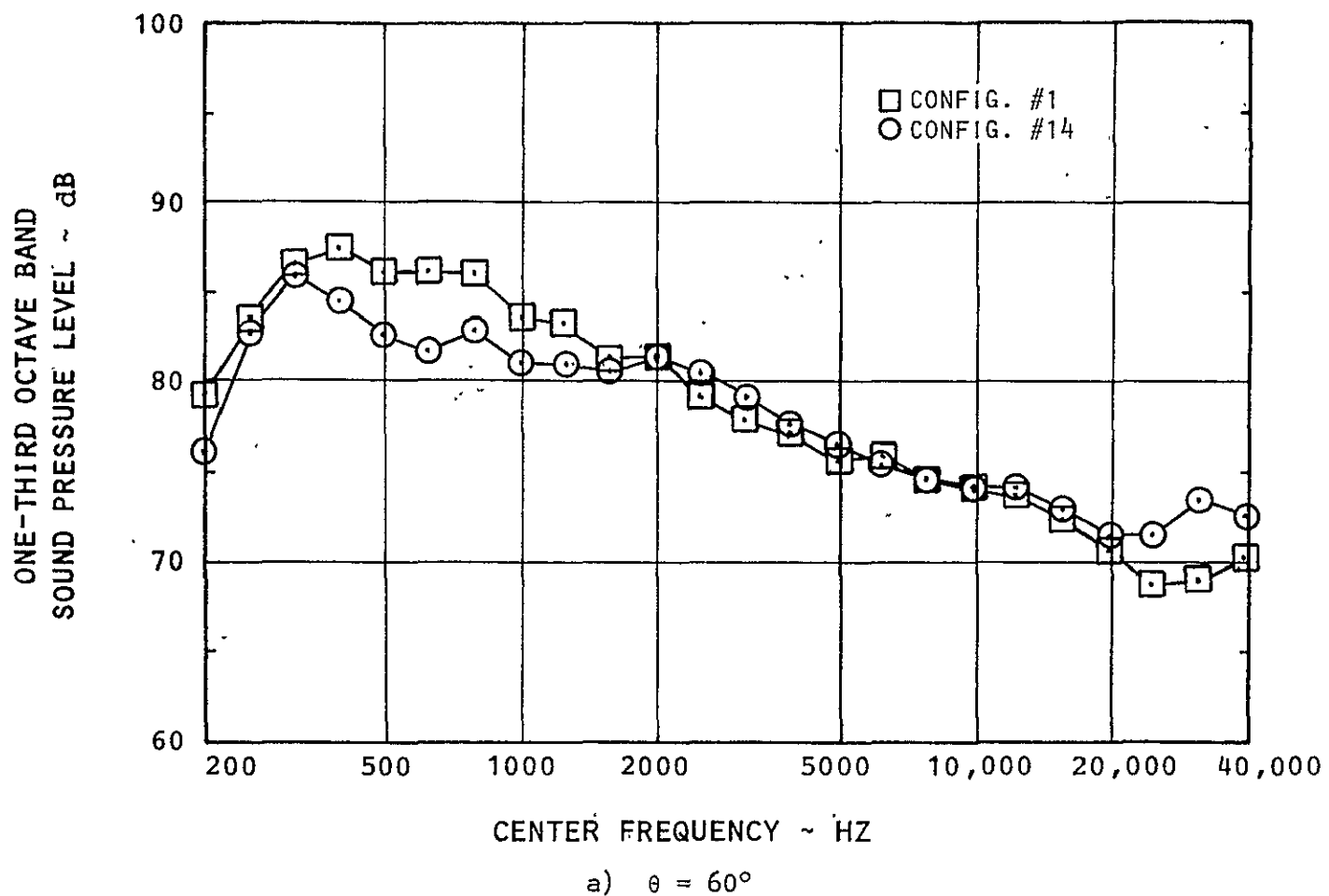
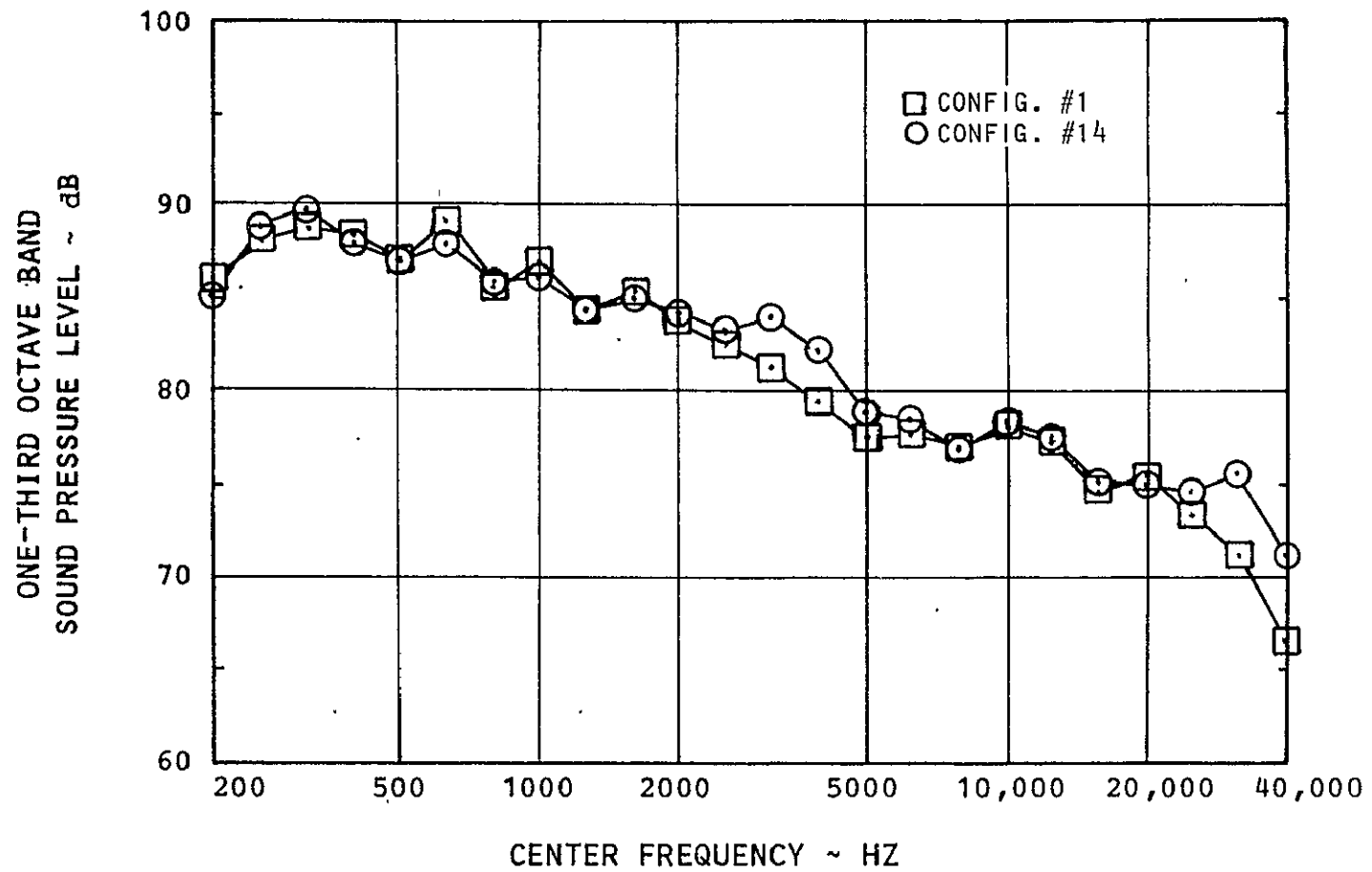


FIGURE 4-83. EFFECT OF NOISE REDUCTION CONFIGURATION 14

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

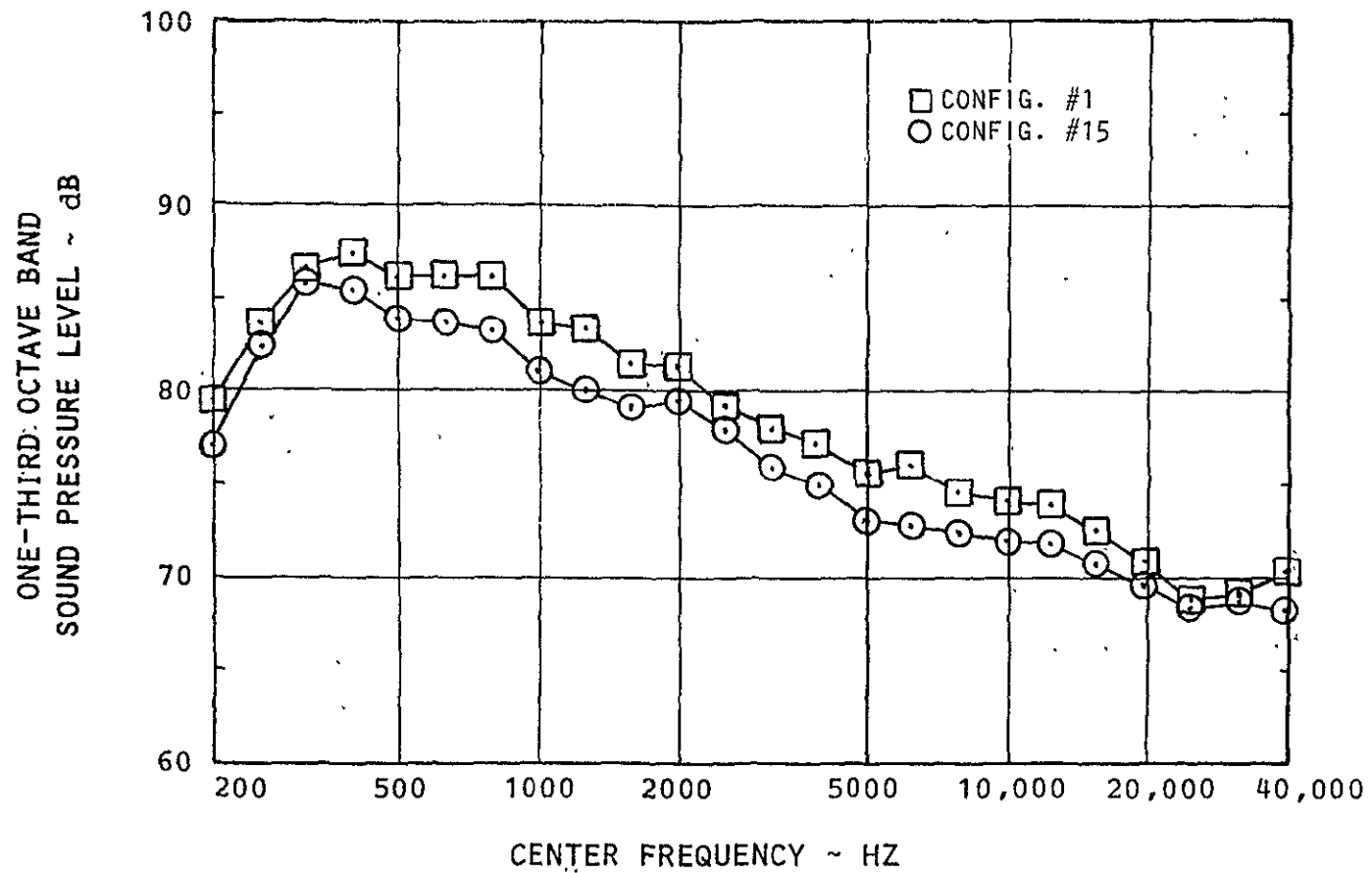


b) $\theta = 120^\circ$

FIGURE 4-83. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

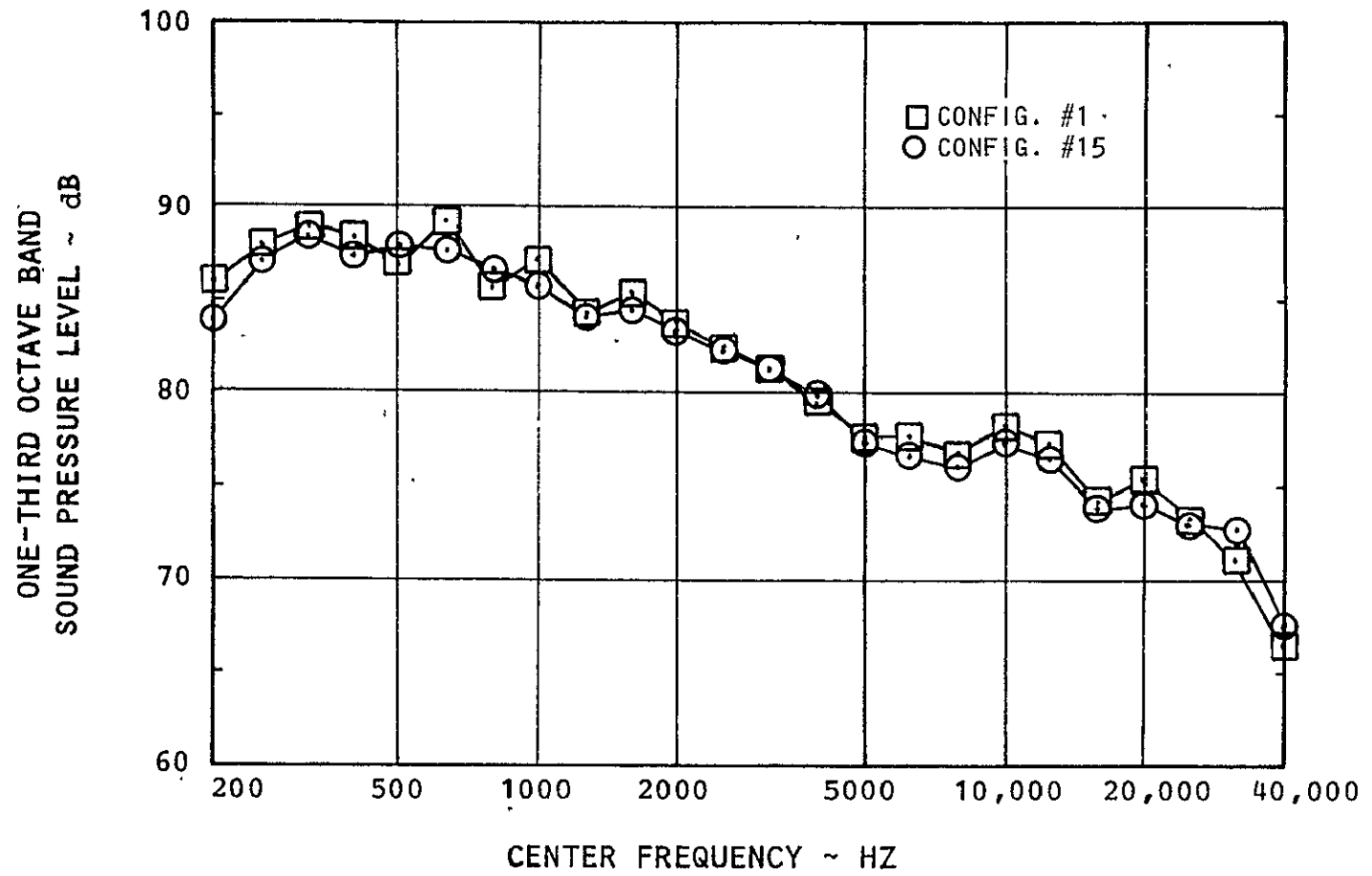
BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)



a) $\theta = 60^\circ$

FIGURE 4-84. EFFECT OF NOISE REDUCTION CONFIGURATION 15

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS



b) $\theta = 120^\circ$

FIGURE 4-84. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE $V_{\text{SL0T}} = 129 \text{ M/S}$

$\phi = 90^\circ$ (FLYOVER PLANE)

$\delta_f = 30^\circ$

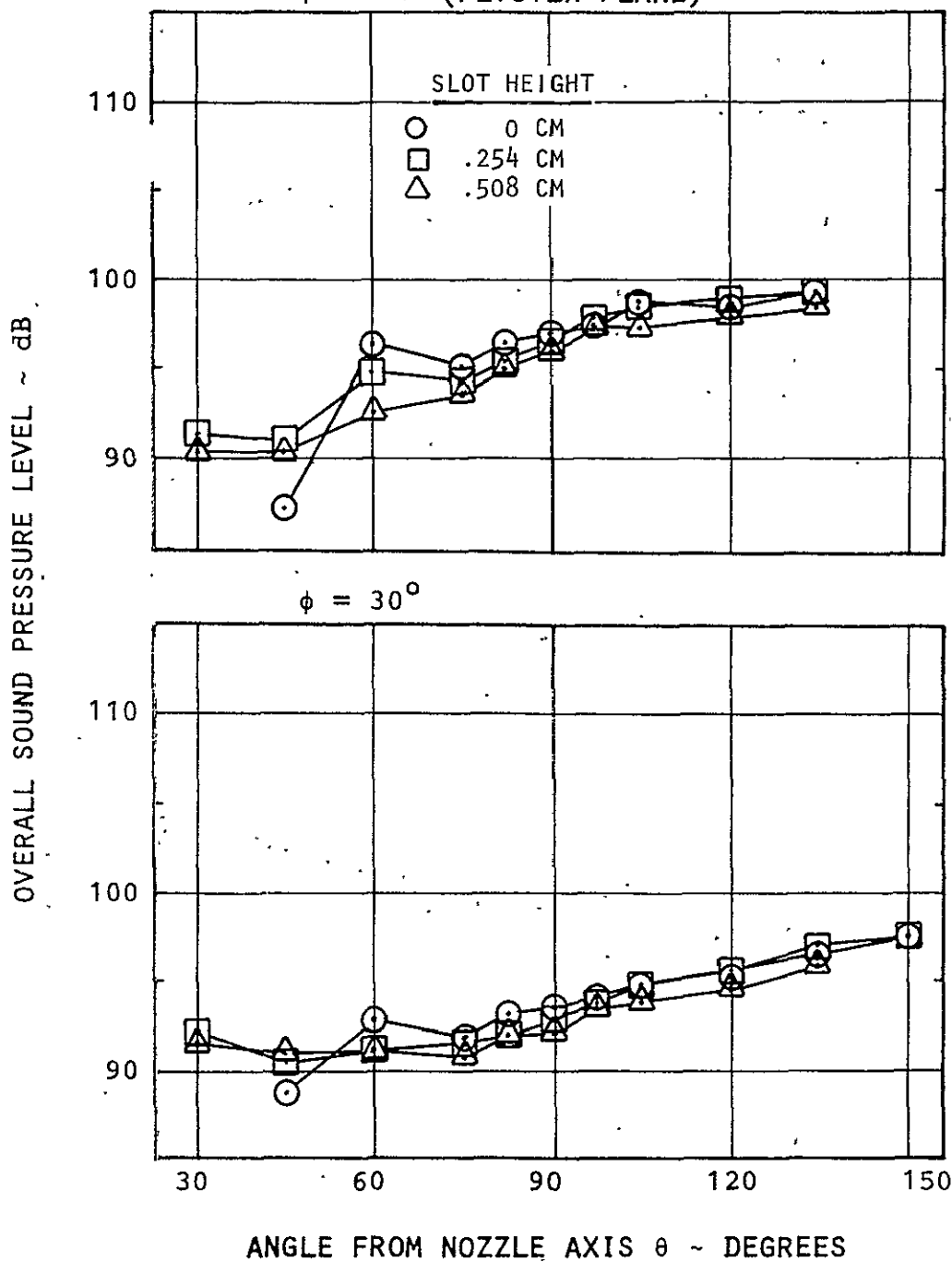


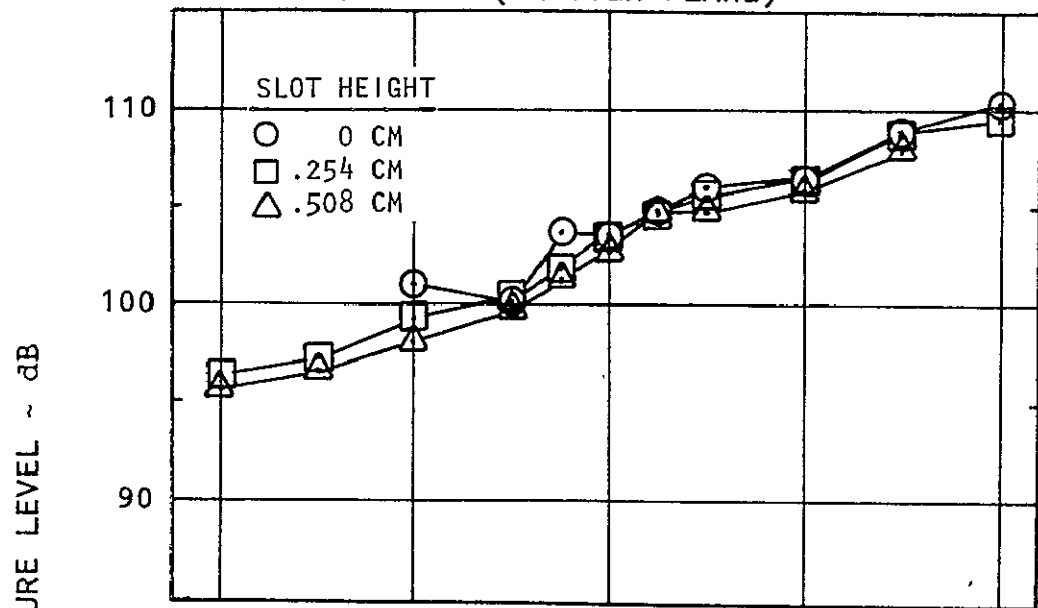
FIGURE 4-85. EFFECT OF SLOT HEIGHT WITH $V_j = 215 \text{ M/S}$

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

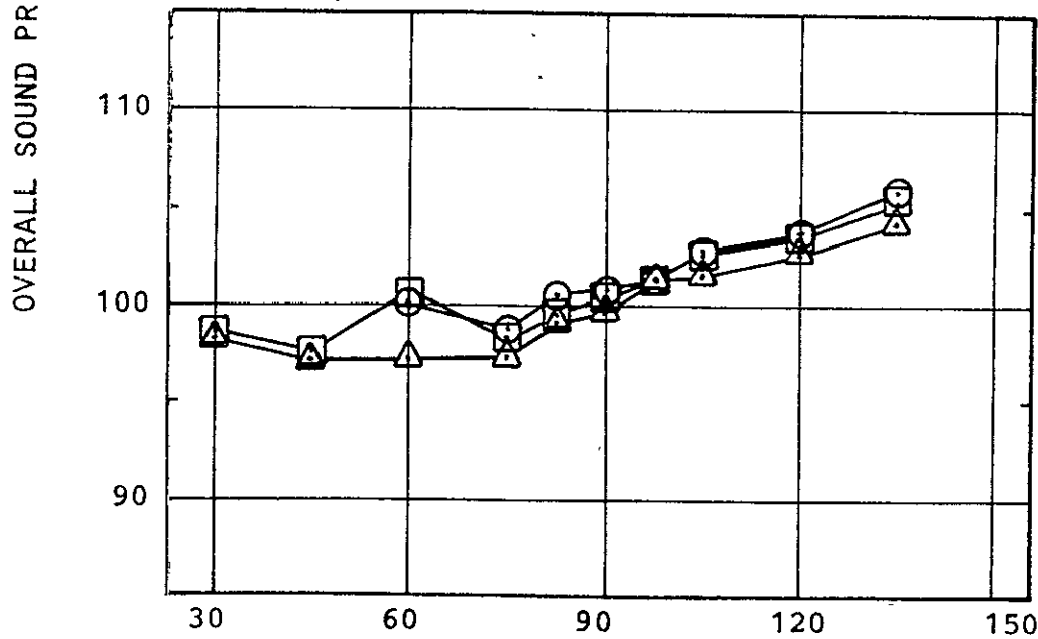
AR8 NOZZLE $V_{\text{slot}} = 171 \text{ M/S}$

$\phi = 90^\circ$ (FLYOVER PLANE)

$\delta_f = 30^\circ$



$\phi = 30^\circ$



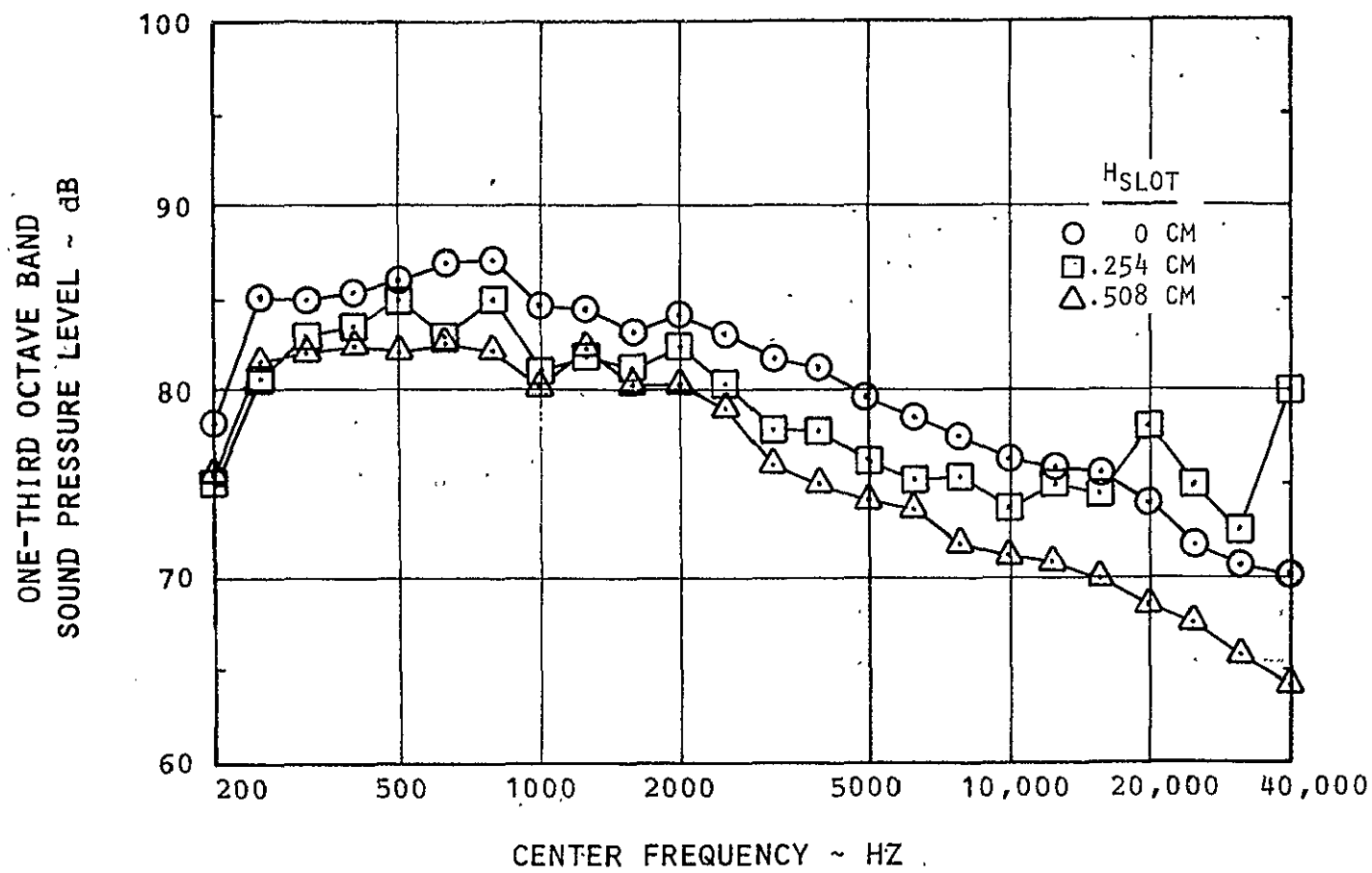
ANGLE FROM NOZZLE AXIS $\theta \sim$ DEGREES

FIGURE 4-86. EFFECT OF SLOT HEIGHT WITH $V_j = 285 \text{ M/S}$

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE $V_{\text{SLOT}} = 129 \text{ M/S}$ $V_J = 215 \text{ M/S}$

$\delta_f = 30^\circ$

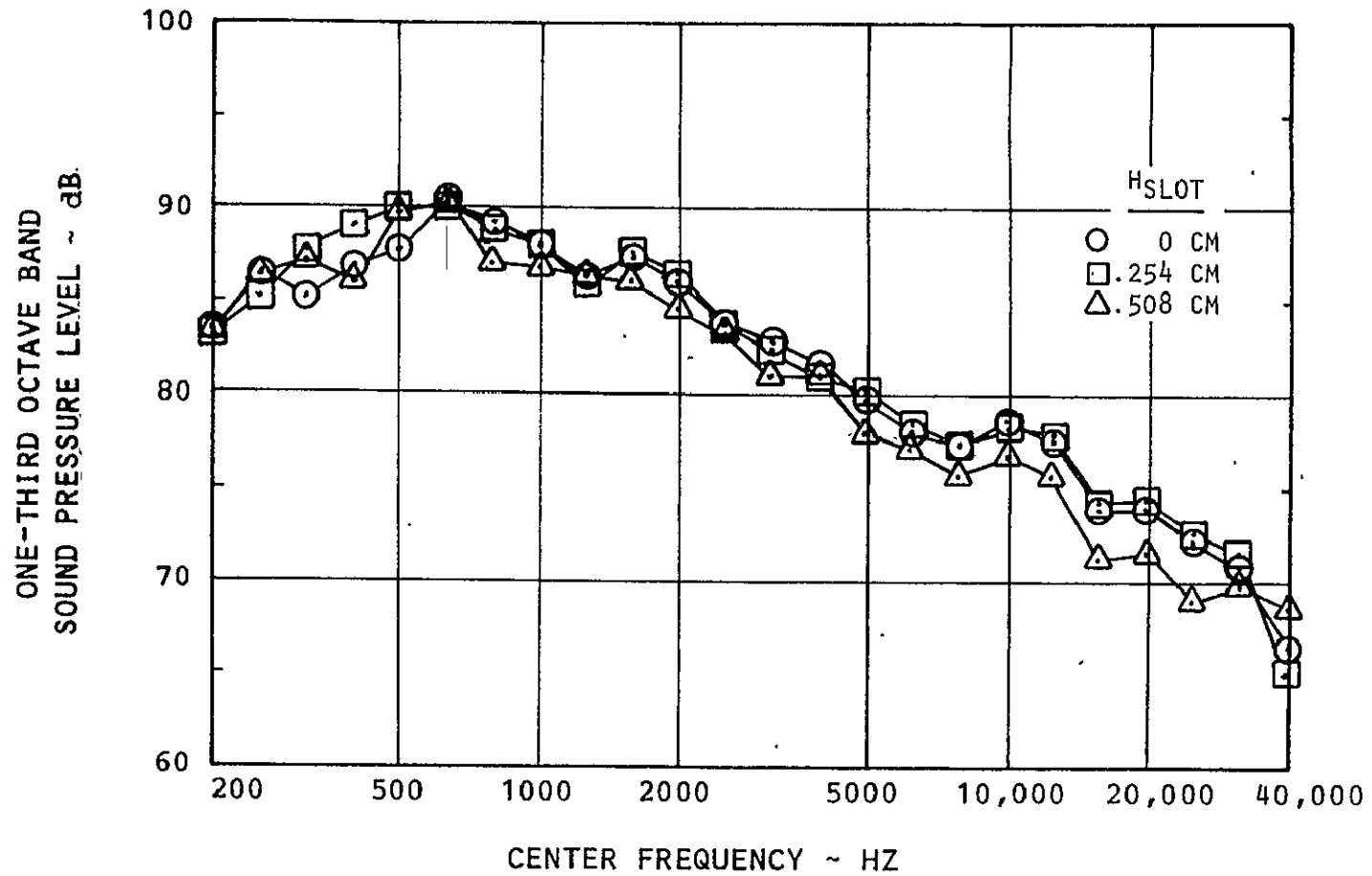


a) $\theta = 60^\circ$

FIGURE 4-87. EFFECT OF SLOT HEIGHT ON FLYOVER SPECTRUM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

$V_{\text{SLOT}} = 129 \text{ M/S}$



b) $\theta = 120^\circ$

FIGURE 4-87. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

$$\phi = 30^\circ \quad V_{\text{SLOT}} = 129 \text{ M/S} \quad V_J = 215 \text{ M/S}$$

$$\text{AR8 NOZZLE} \quad \delta_f = 30^\circ$$

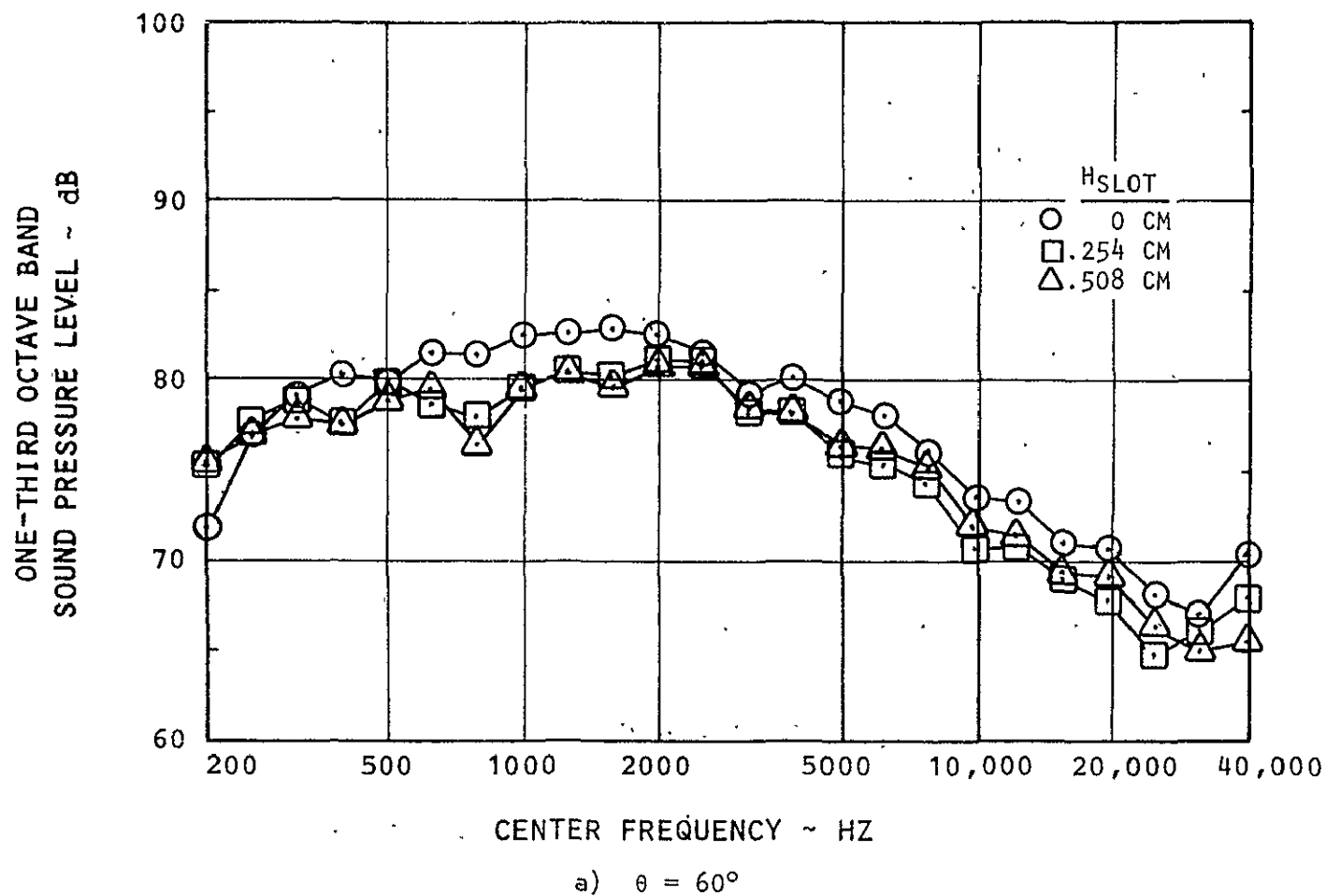
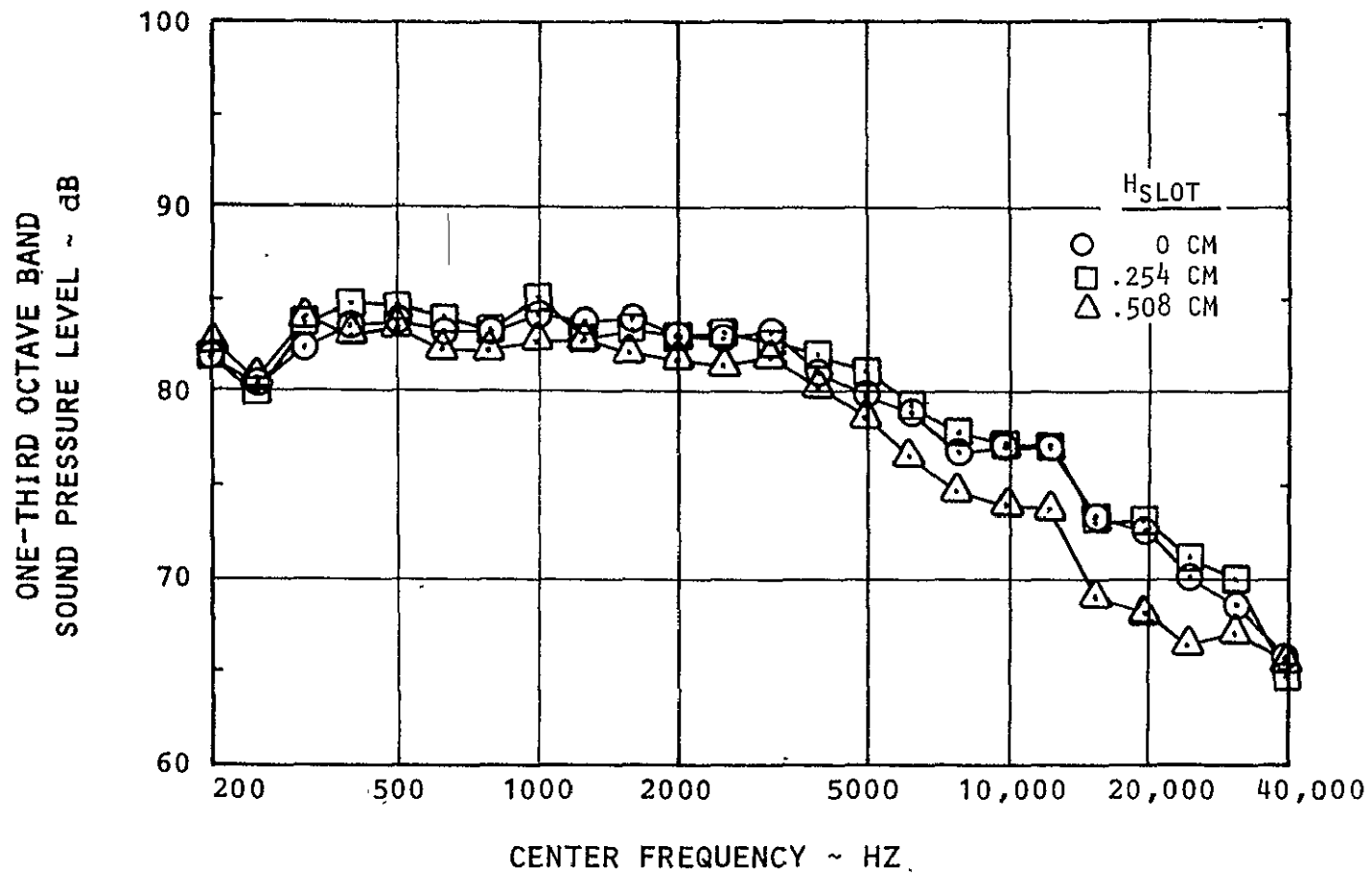


FIGURE 4-88. EFFECT OF SLOT HEIGHT ON SIDELINE SPECTRUM

C-6

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

$\phi = 30^\circ$ $V_{\text{SLOT}} = 129 \text{ M/S}$



b) $\theta = 120^\circ$

FIGURE 4-88. (CONCLUDED)

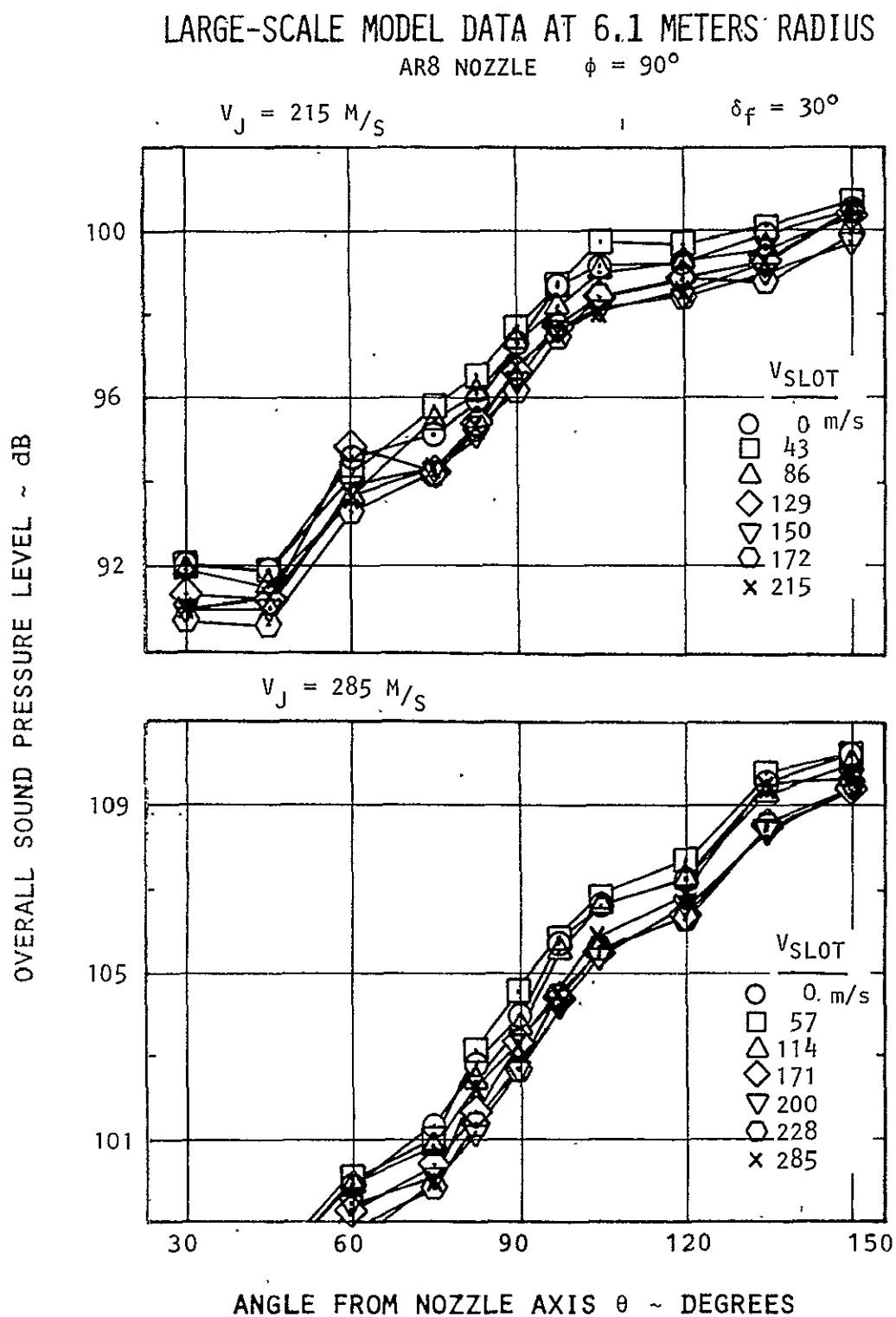


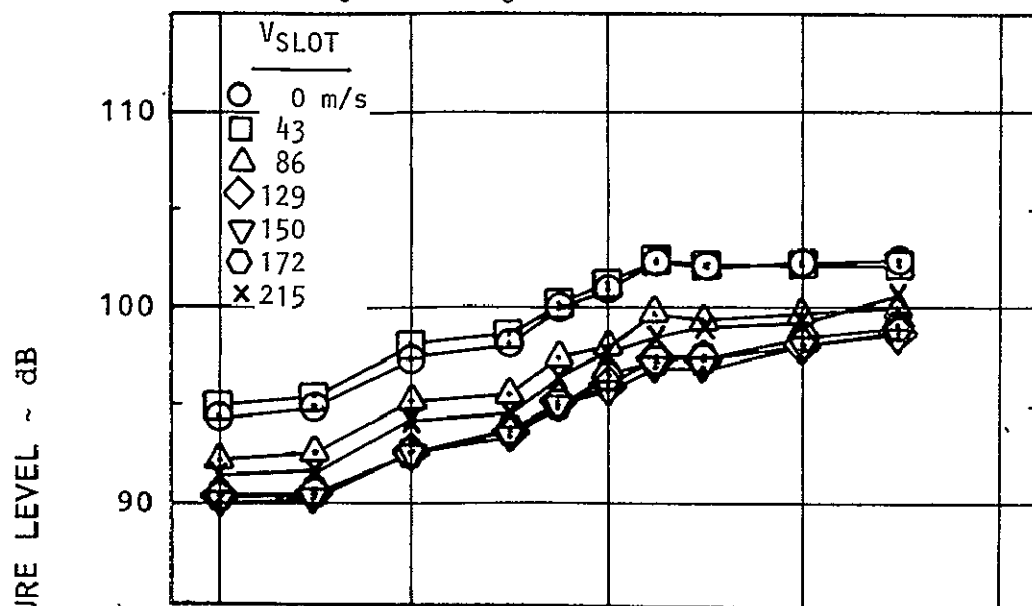
FIGURE 4-89. EFFECT OF TRAILING EDGE BLOWING VELOCITY ON DIRECTIVITY WITH 0.254 CM SLOT HEIGHT

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE $\phi = 90^\circ$

$V_J = 215 \text{ M/S}$

$\delta_f = 30^\circ$



$V_J = 285 \text{ M/S}$

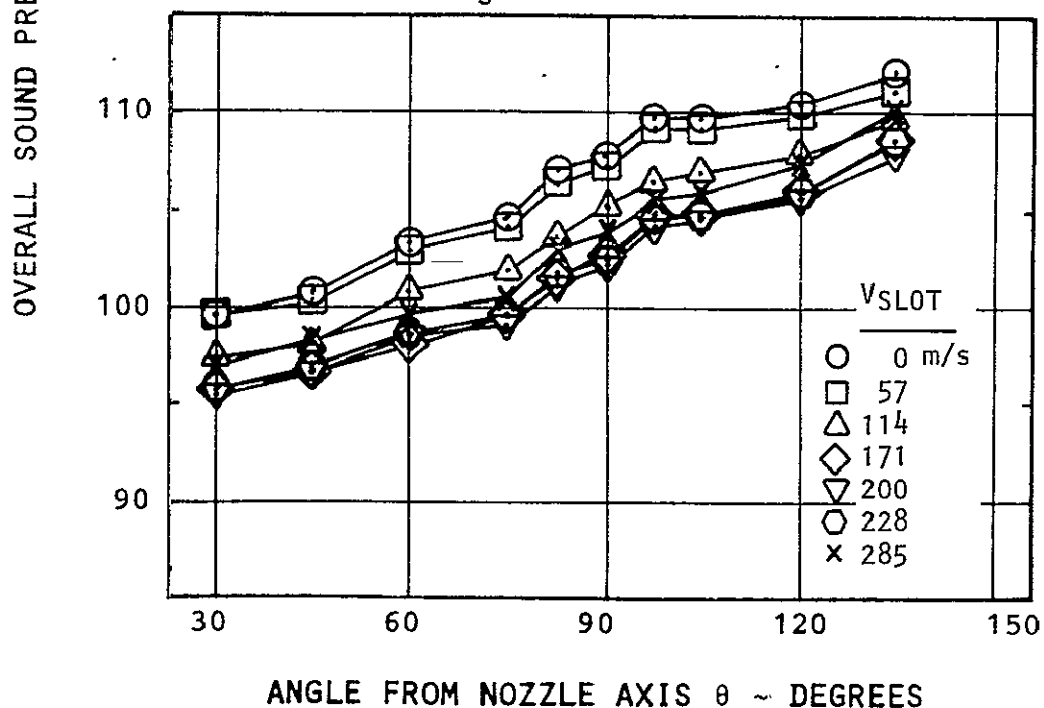


FIGURE 4-90. EFFECT OF TRAILING EDGE BLOWING VELOCITY WITH 0.508 SLOT HEIGHT

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE

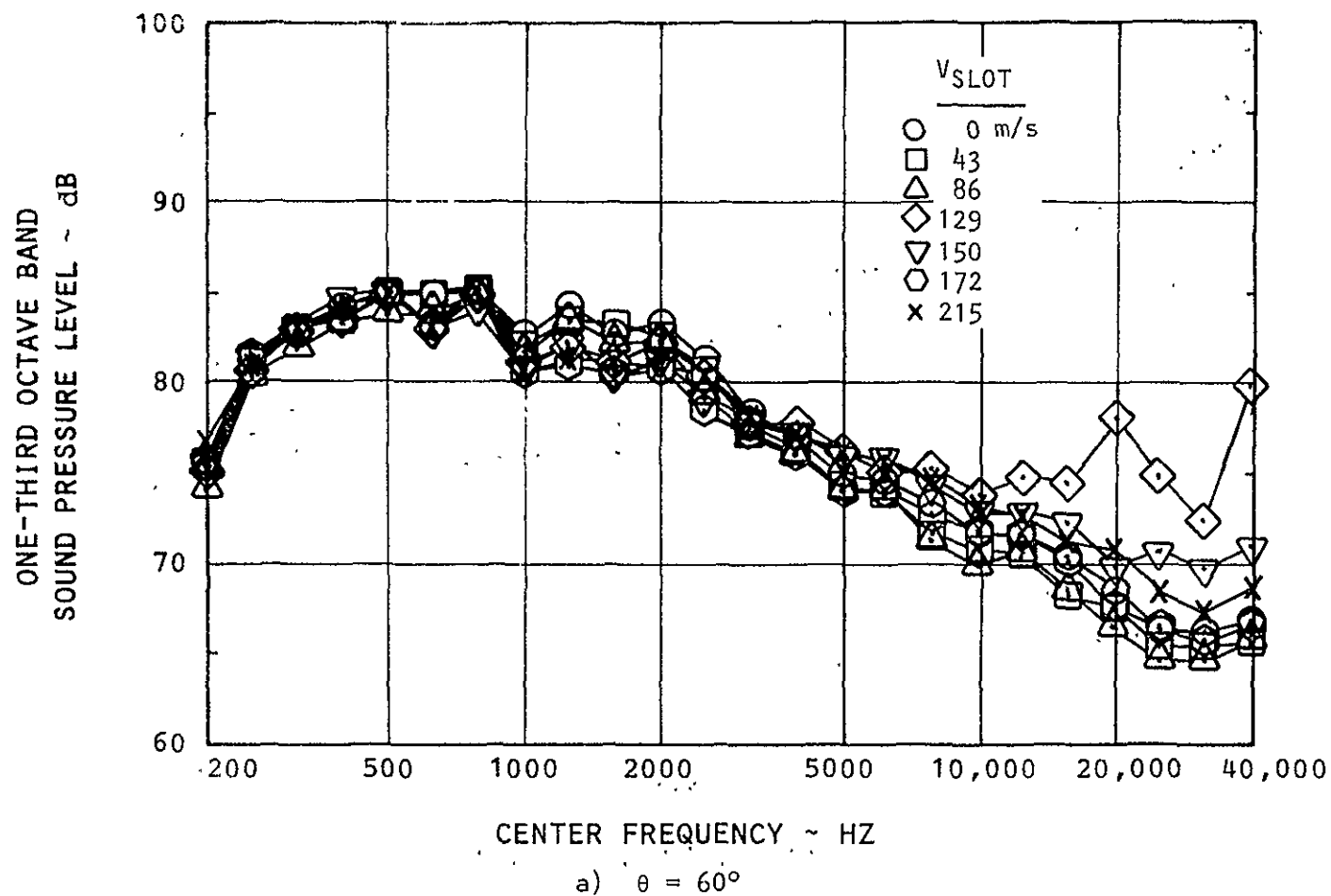
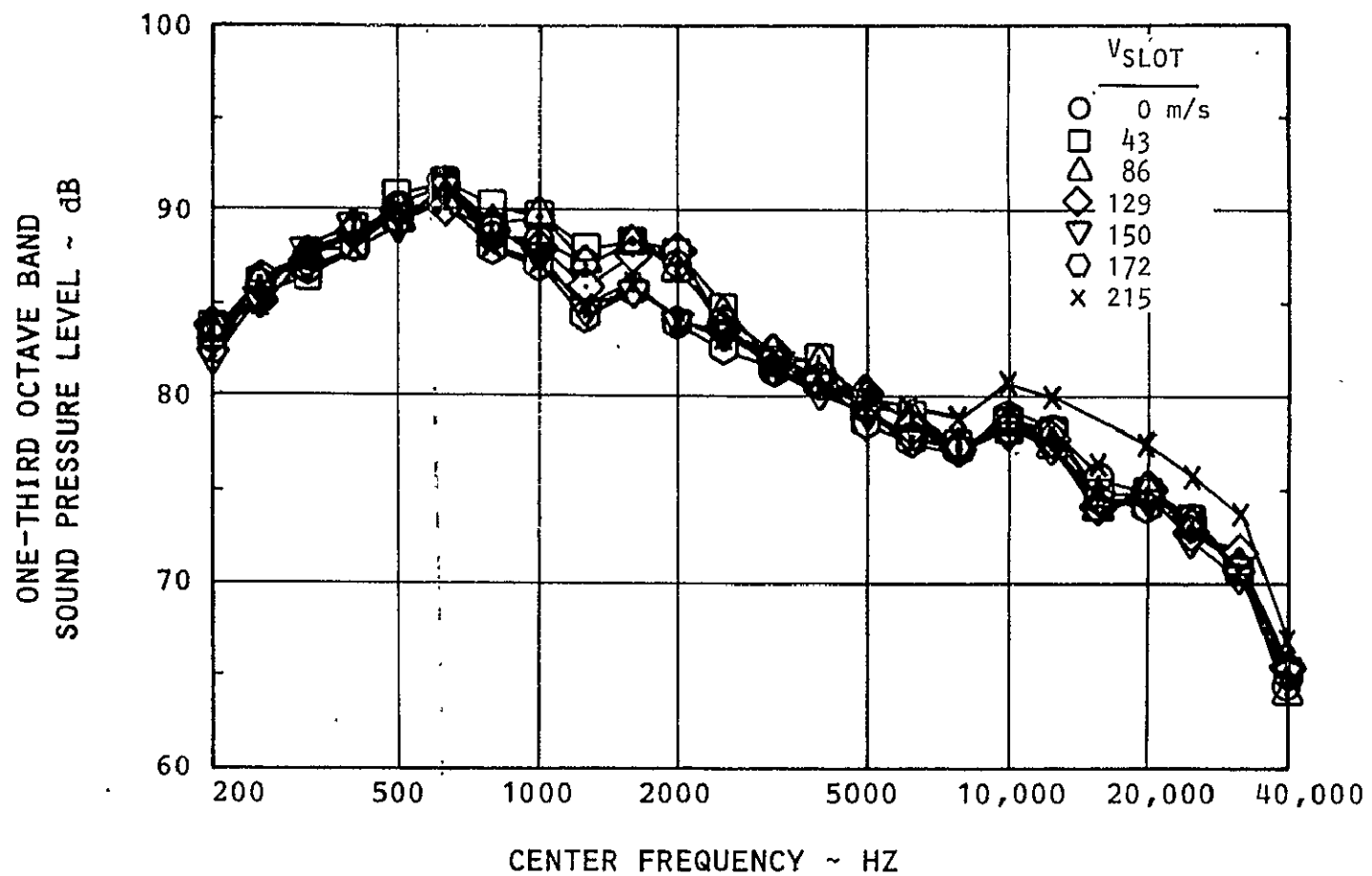
 $\phi = 90^\circ$ $\delta_f = 30^\circ$ 

FIGURE 4-91. EFFECT OF TRAILING EDGE BLOWING VELOCITY ON SPECTRUM WITH $V_j = 215$ M/S AND $H_{\text{SLOT}} = 0.254$ CM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE



b) $\theta = 120^\circ$

FIGURE 4-91. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE

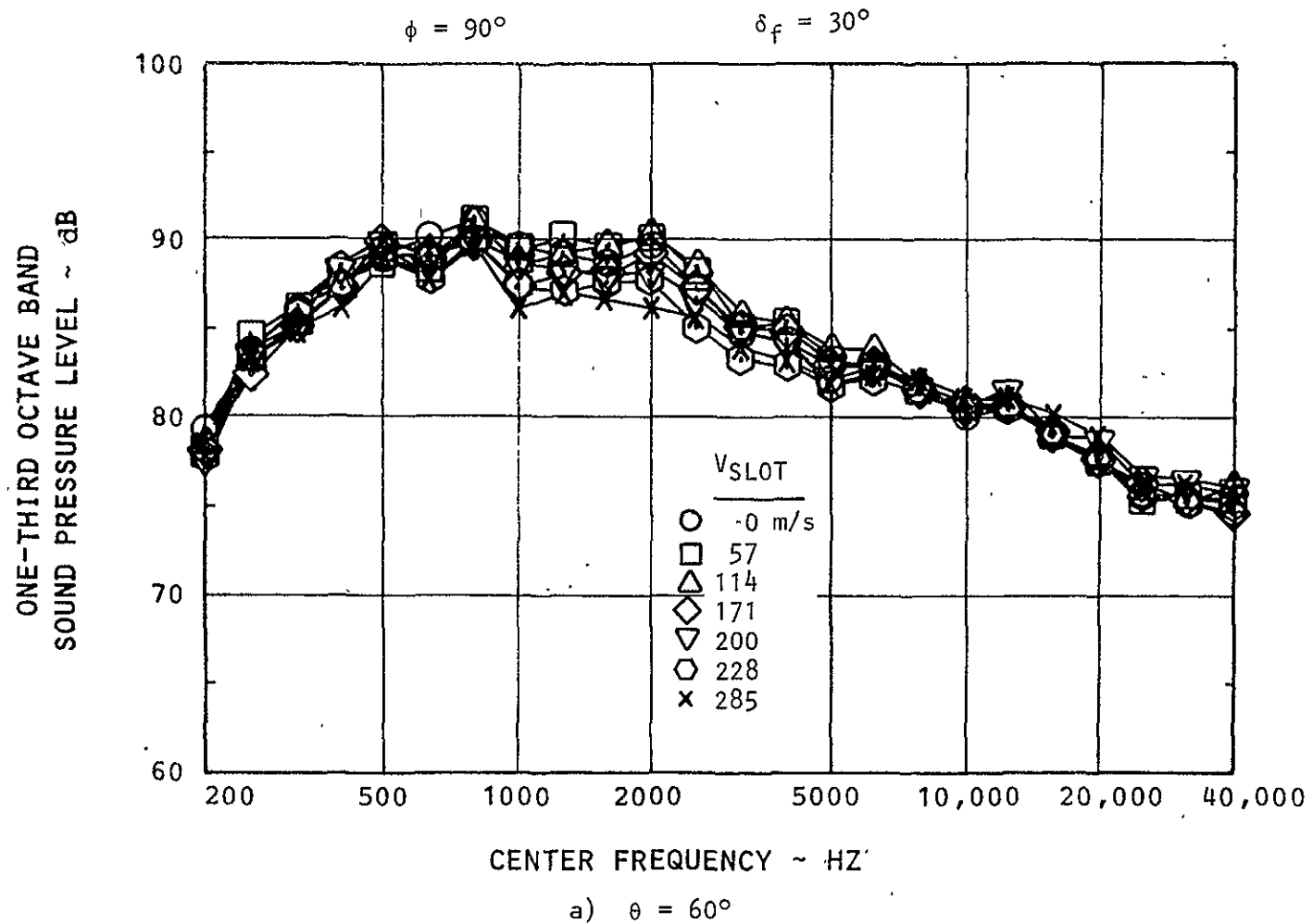


FIGURE 4-92. EFFECT OF TRAILING EDGE BLOWING VELOCITY ON SPECTRUM FOR $V_j = 285$ M/S AND SLOT HEIGHT = 0.254 CM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE

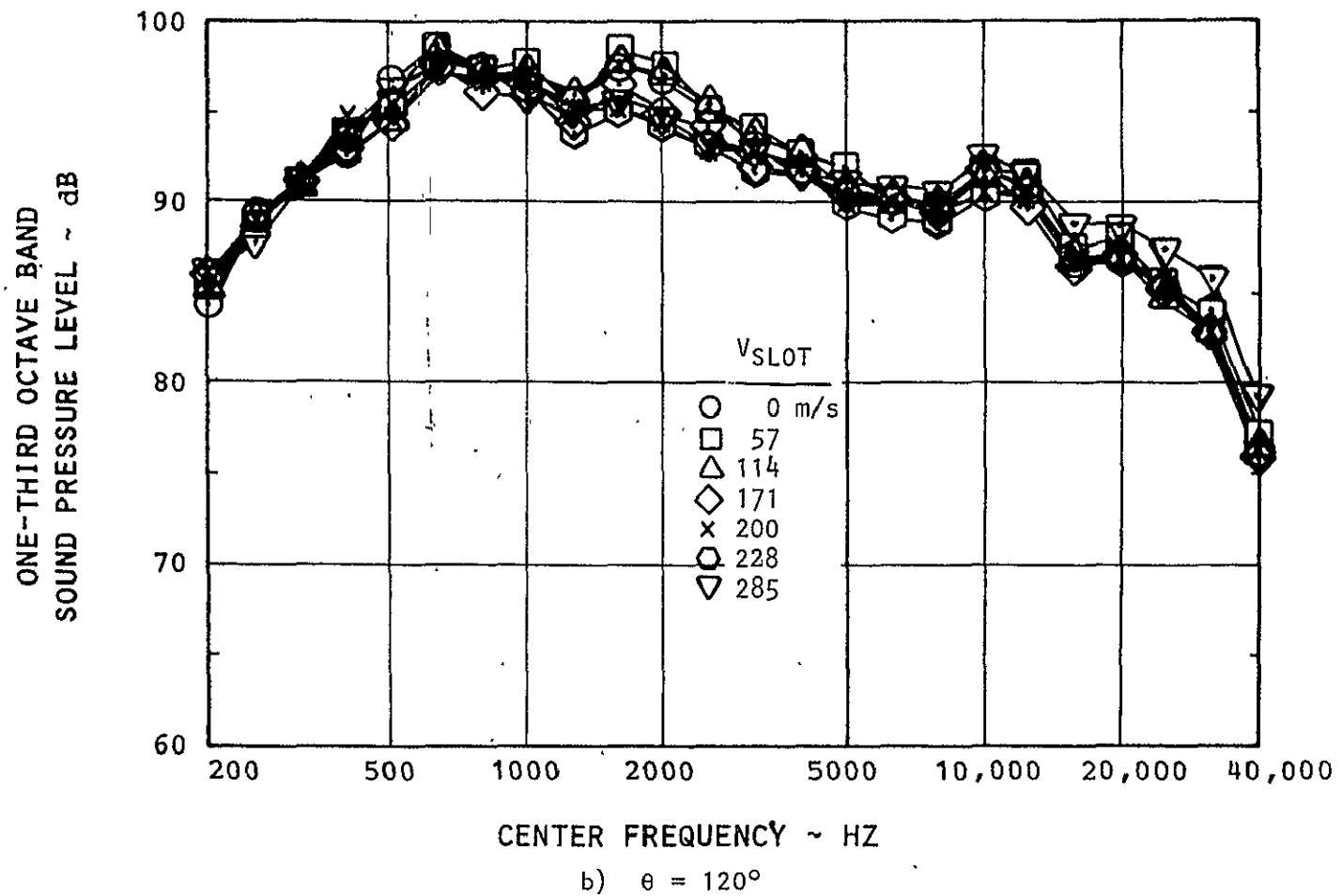


FIGURE 4-92. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE

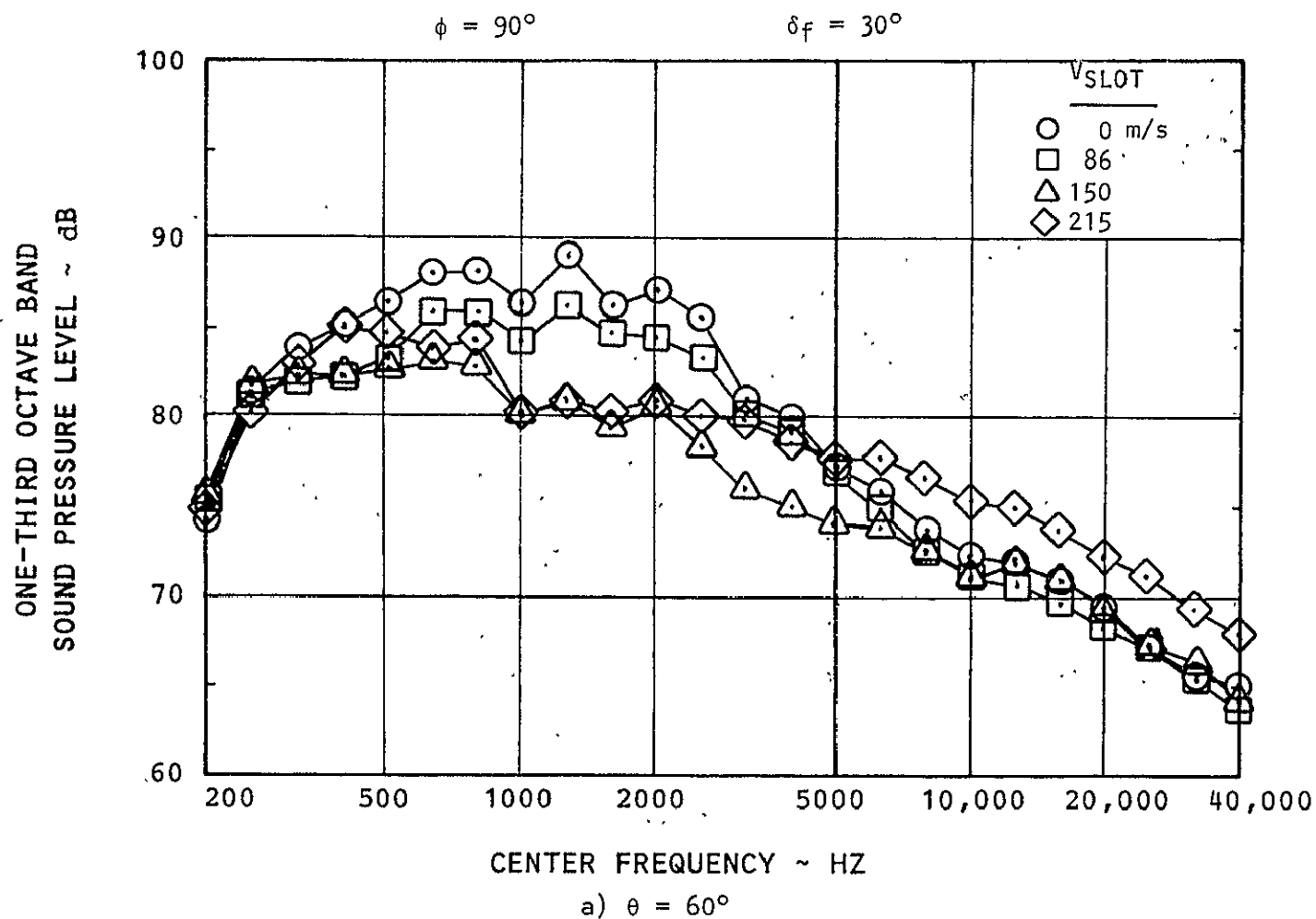


FIGURE 4-93. EFFECT OF TRAILING EDGE BLOWING VELOCITY ON SPECTRUM
FOR $V_j = 215$ M/S AND SLOT HEIGHT = 0.508 CM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE

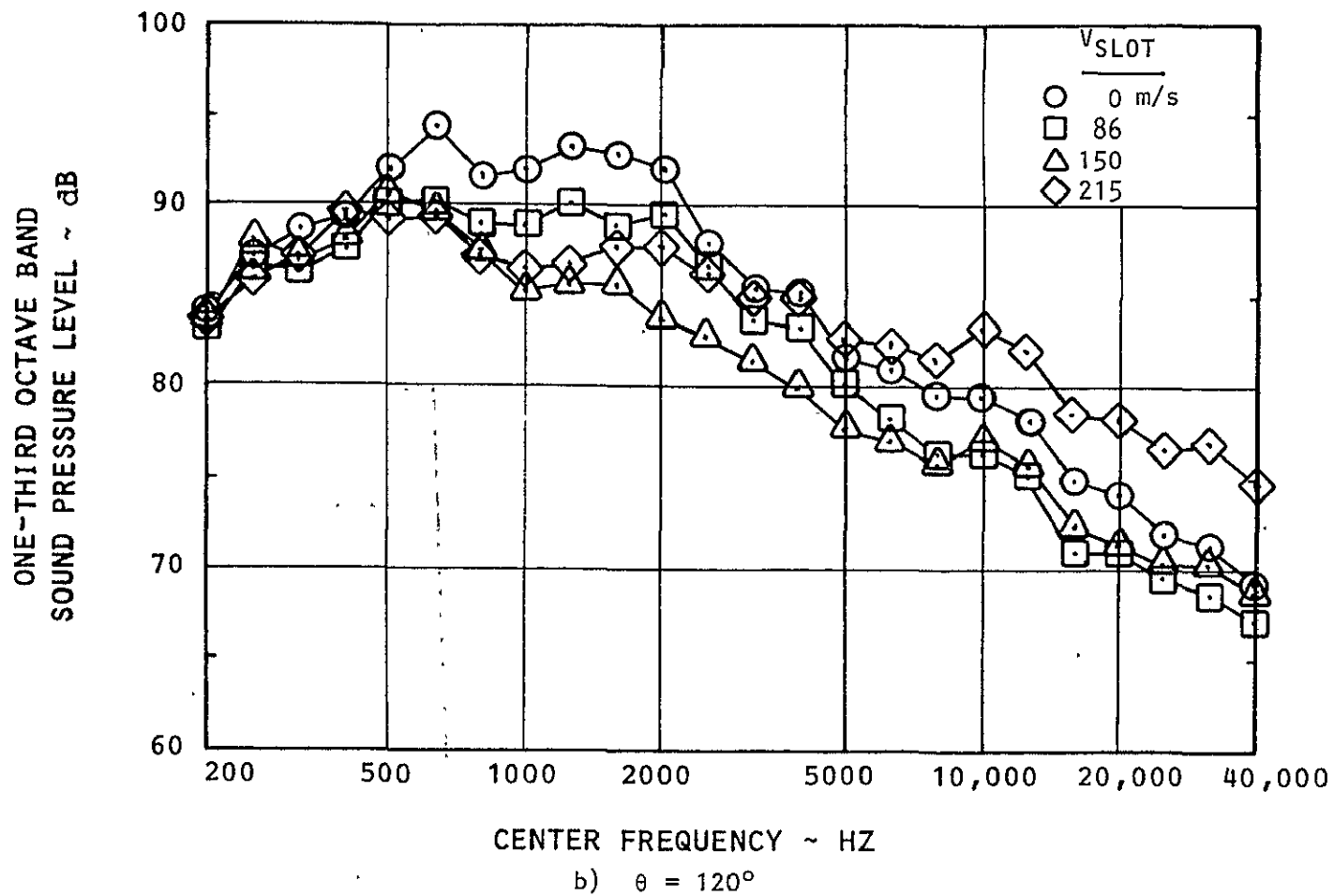


FIGURE 4-93. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE

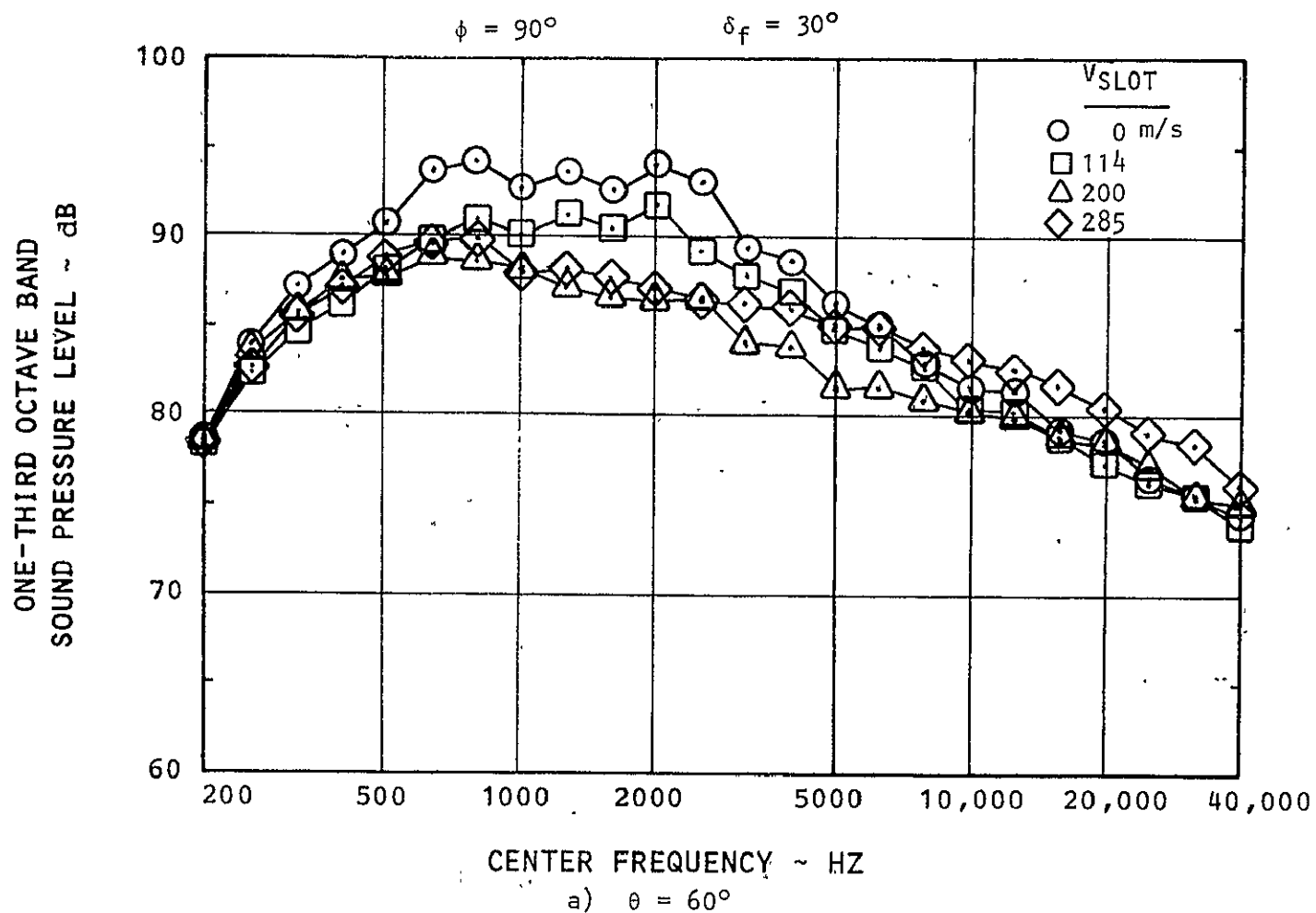
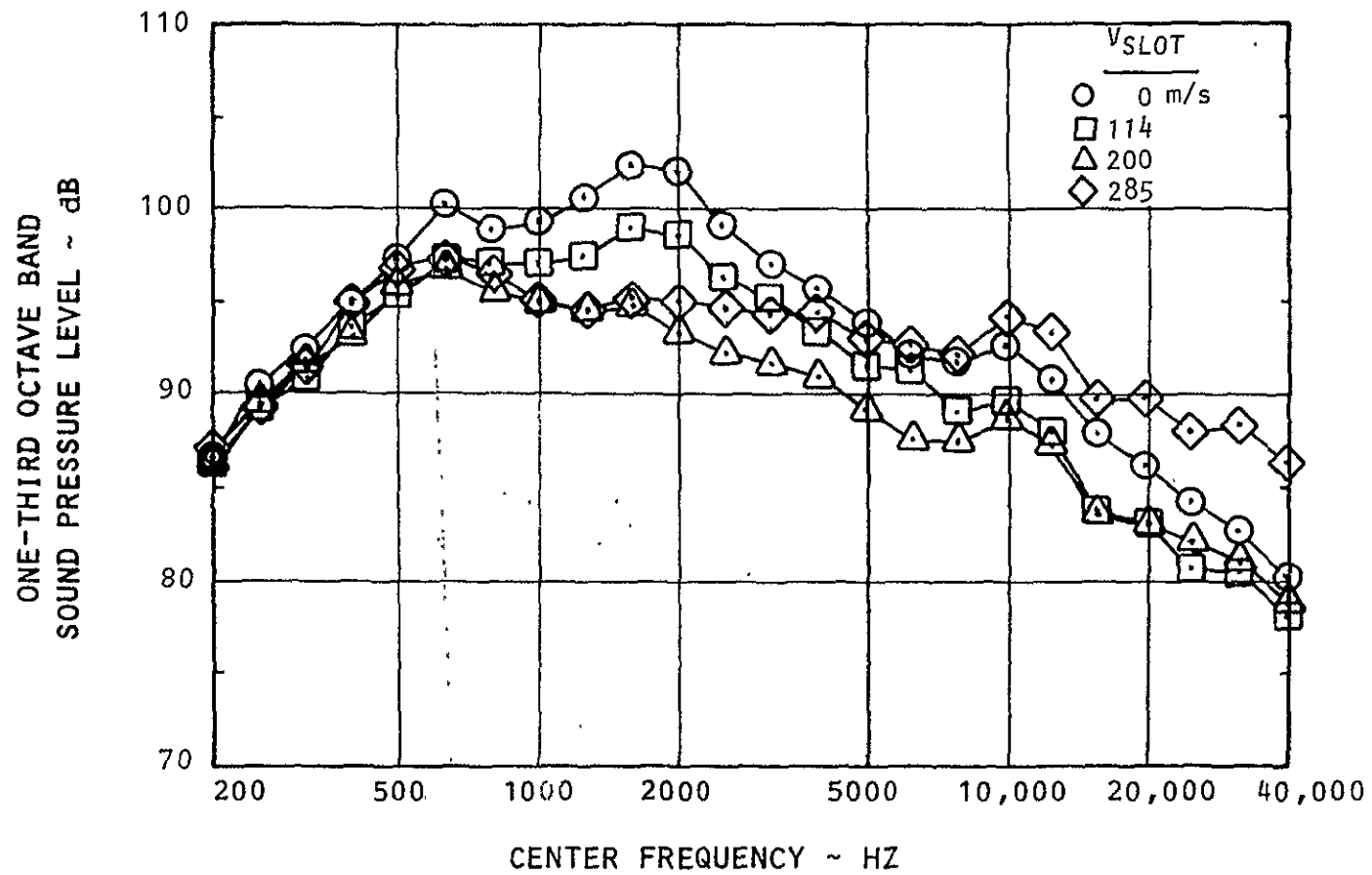


FIGURE 4-94. EFFECT OF TRAILING EDGE BLOWING VELOCITY ON SPECTRUM
WITH $V_i = 285$ M/S AND SLOT HEIGHT = 0.508 CM

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR8 NOZZLE



b) $\theta = 120^\circ$

FIGURE 4-94. (CONCLUDED)

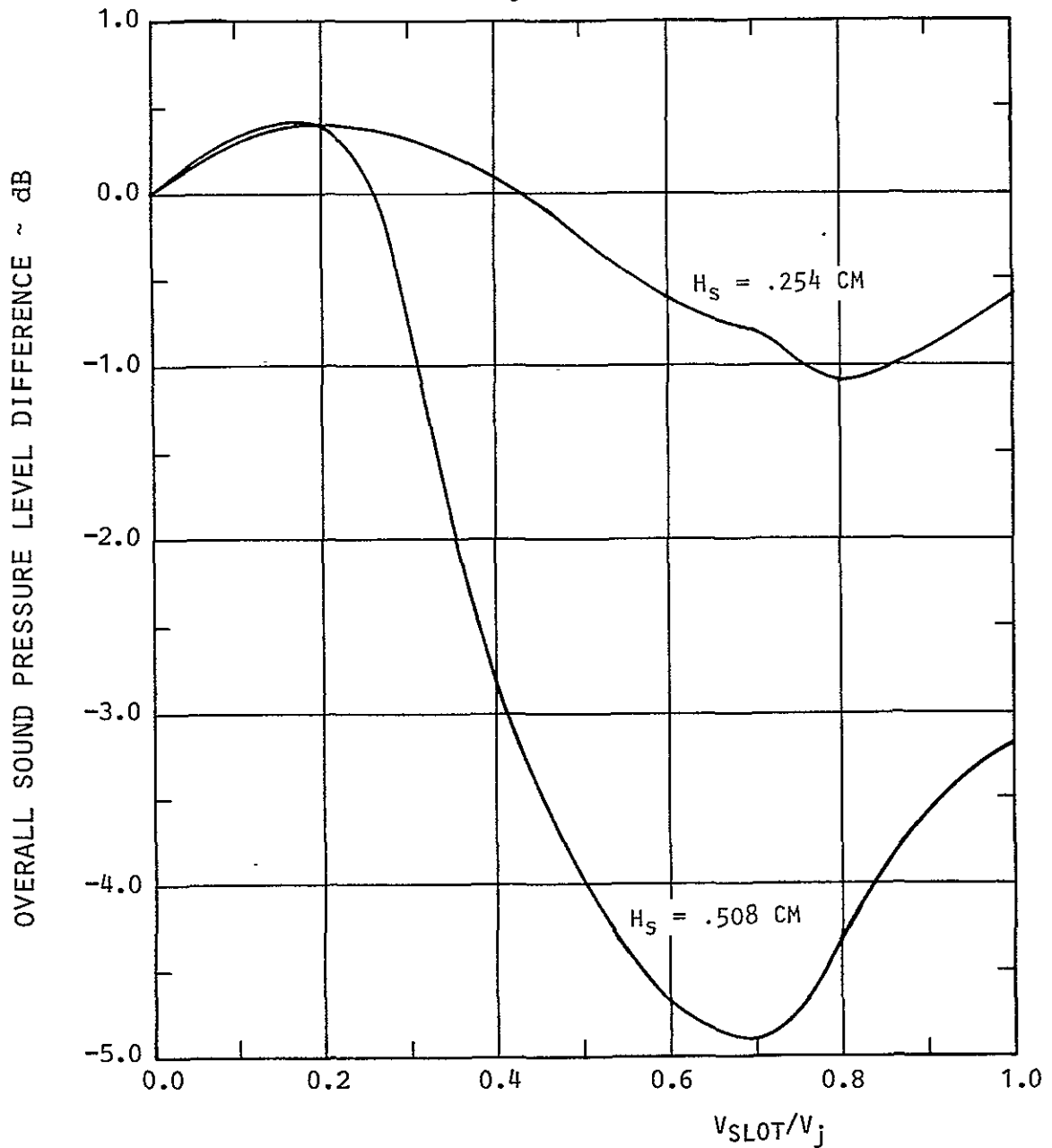
LARGE-SCALE MODEL AT 6.1 METERS RADIUS

AR8 NOZZLE

$\delta_f = 30^\circ$

$\theta = 90^\circ$

$V_J = 215 \text{ TO } 285 \text{ M/S}$

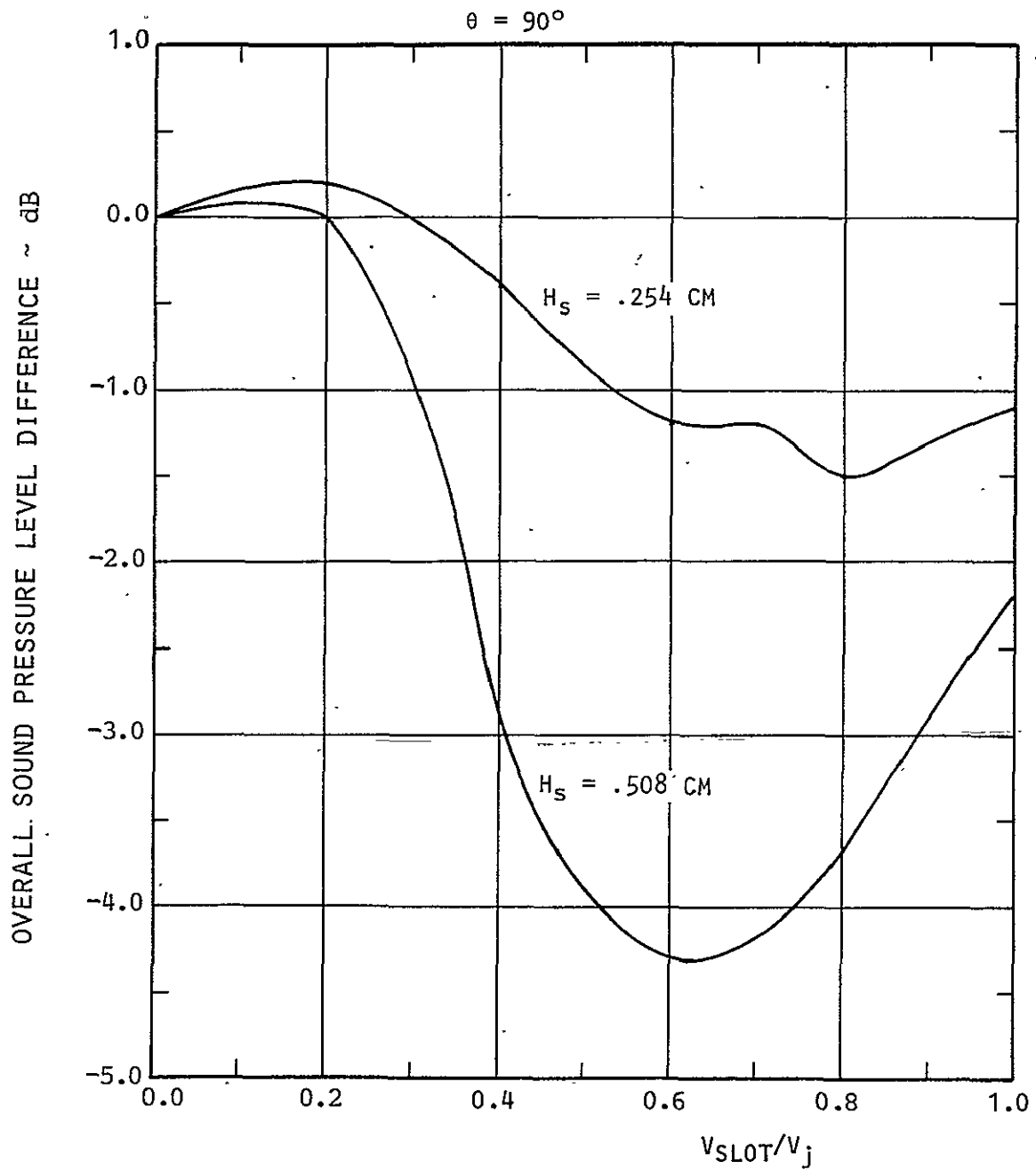


a) FLYOVER $\phi = 90^\circ$

FIGURE 4-95. OASPL REDUCTION DUE TO TRAILING EDGE SLOT BLOWING

LARGE-SCALE MODEL AT 6.1 METERS RADIUS

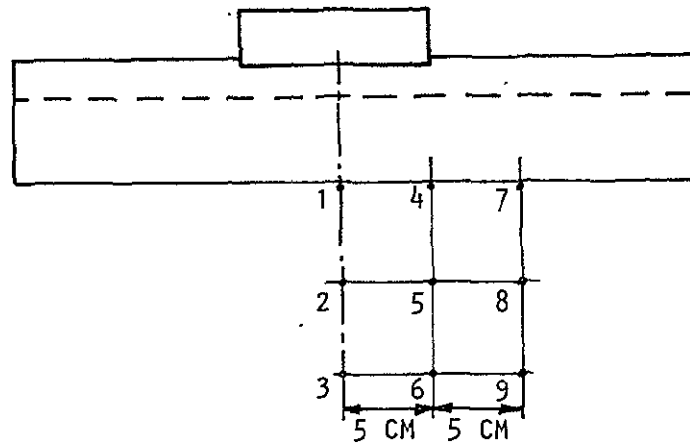
AR8 NOZZLE



b) SIDELINE $\phi = 30^\circ$

FIGURE 4-95. (CONCLUDED)

REAR VIEW



SIDE VIEW

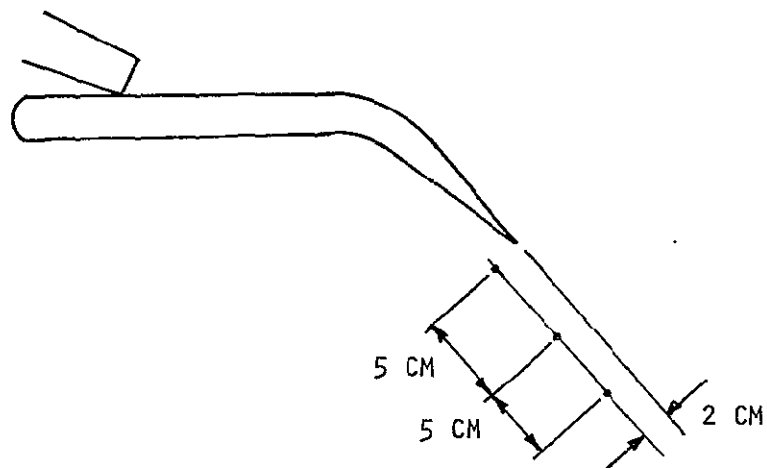


FIGURE 4-96. MICROPHONE POSITIONS FOR NEAR-FIELD NOISE DATA

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

AR2 NOZZLE

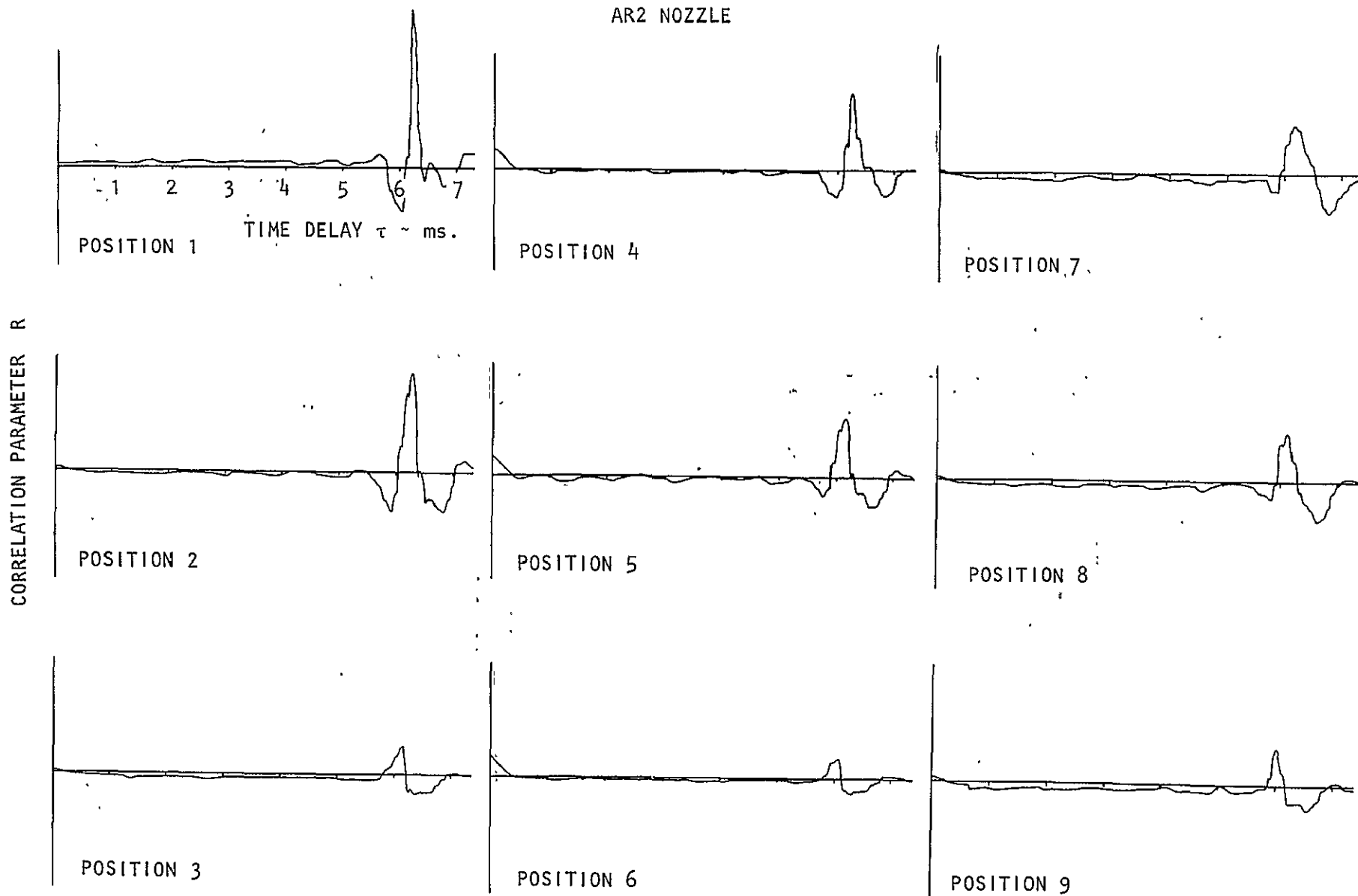


FIGURE 4-97. NEARFIELD/FARFIELD CORRELATIONS

LARGE-SCALE DATA MEASURED ON FLAP SURFACE

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

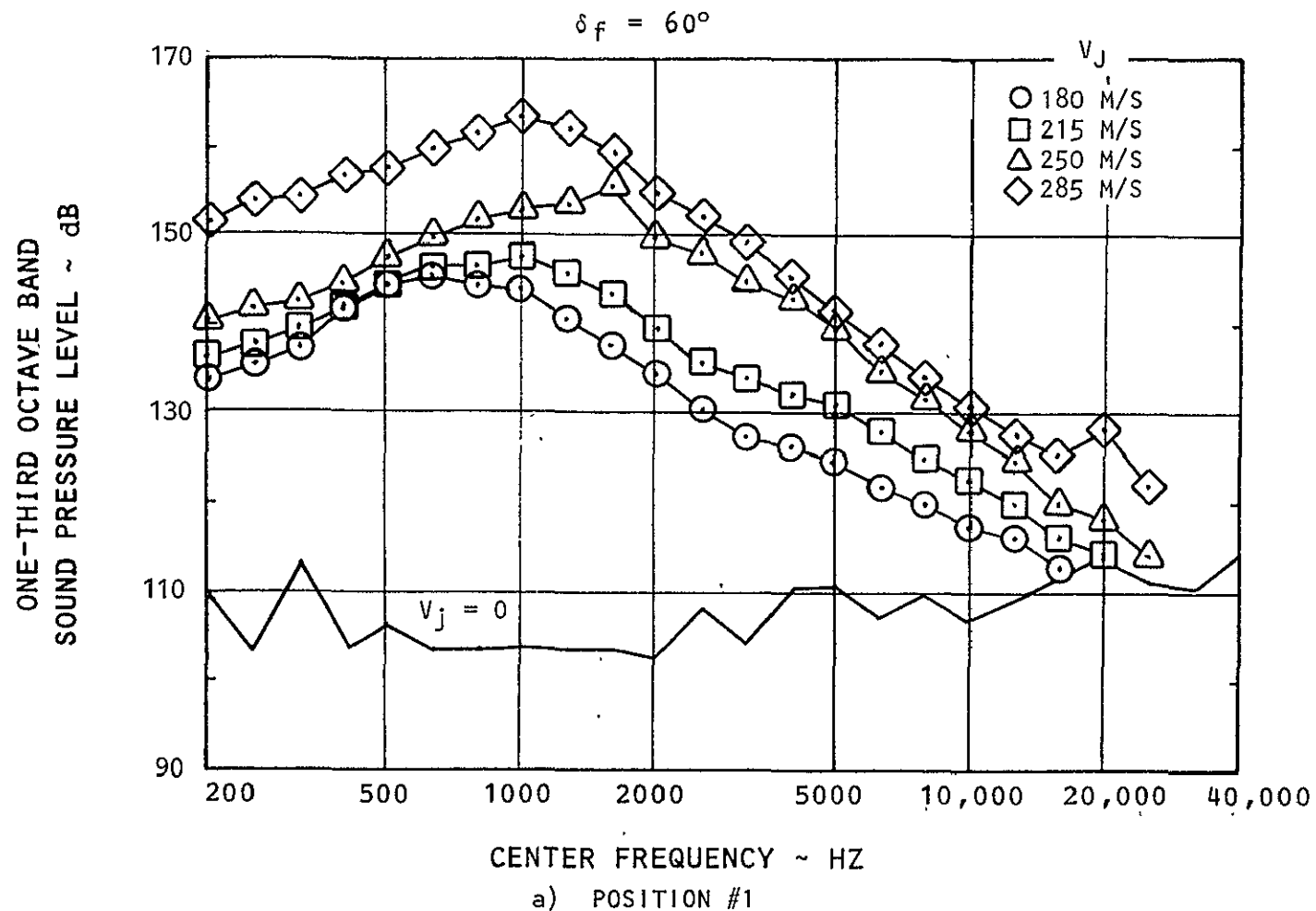


FIGURE 4-98. FLUCTUATING SURFACE PRESSURES FOR AR4 NOZZLE

LARGE-SCALE DATA MEASURED ON FLAP SURFACE

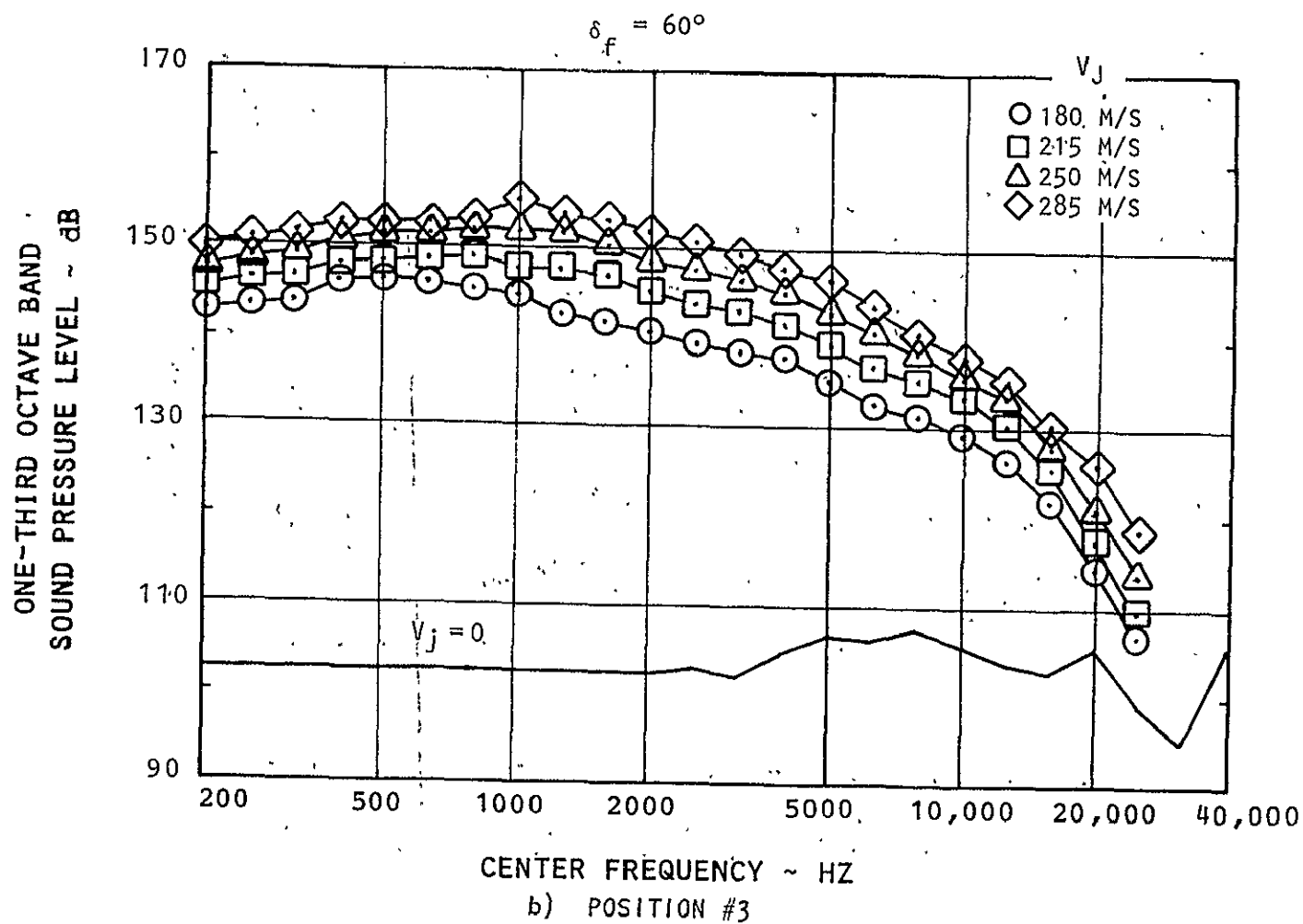


FIGURE 4-98. (CONCLUDED)

LARGE-SCALE DATA MEASURED ON FLAP SURFACE

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

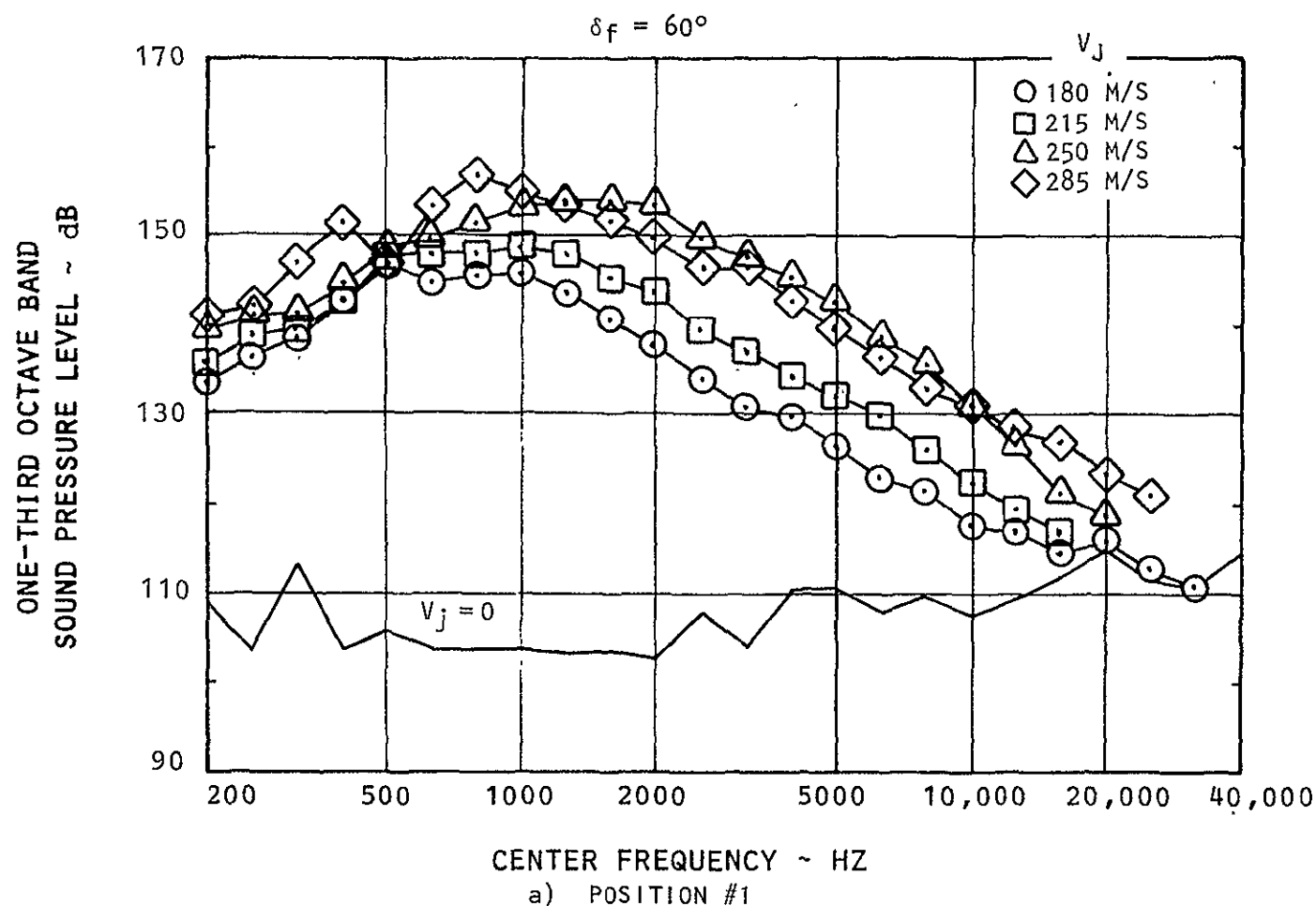
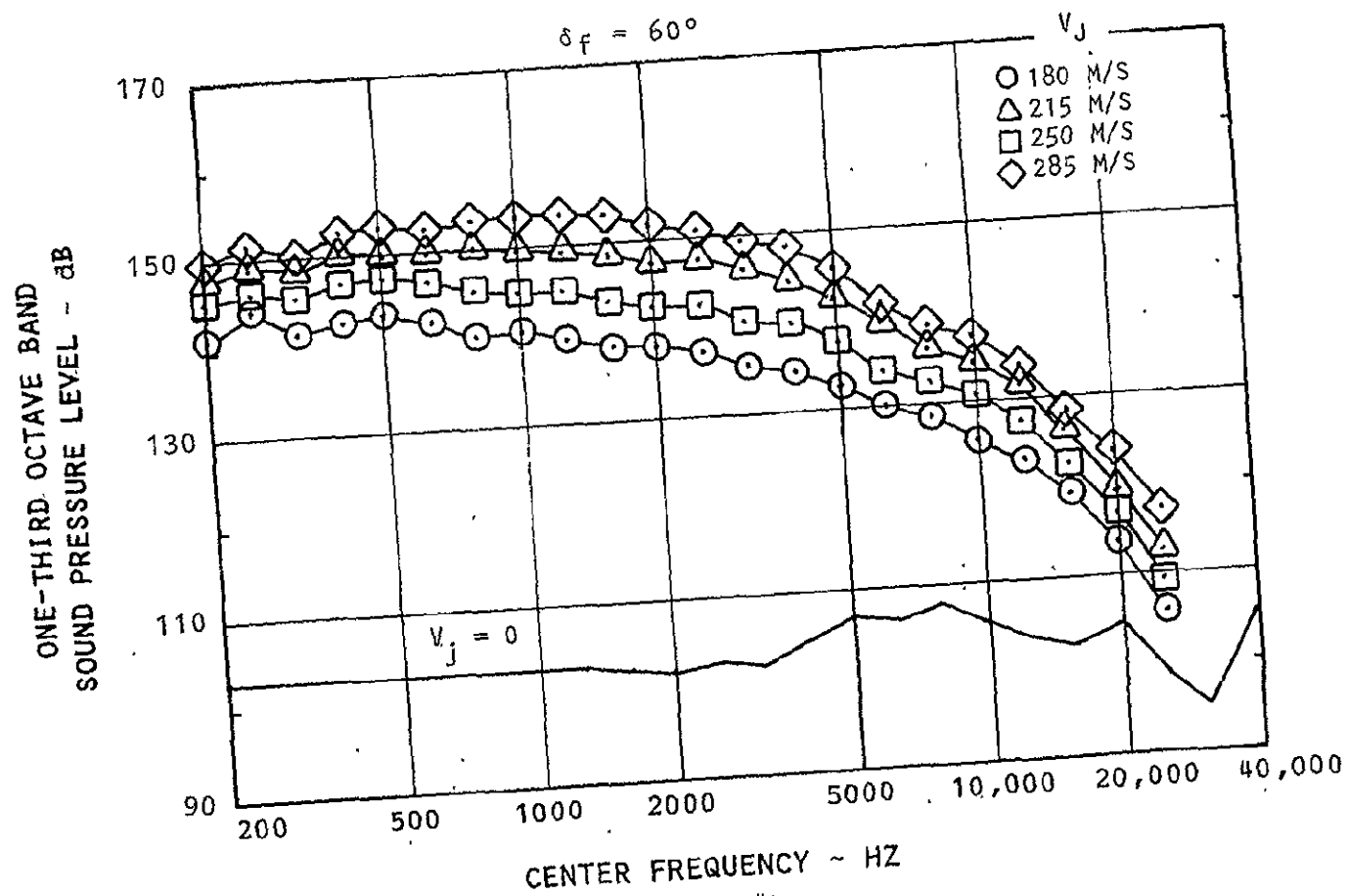


FIGURE 4-99. FLUCTUATING SURFACE PRESSURES FOR AR8 NOZZLE

LARGE-SCALE DATA MEASURED ON FLAP SURFACE



b) POSITION #3

FIGURE 4-99. (CONCLUDED)

LARGE-SCALE DATA MEASURED ON FLAP SURFACE BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

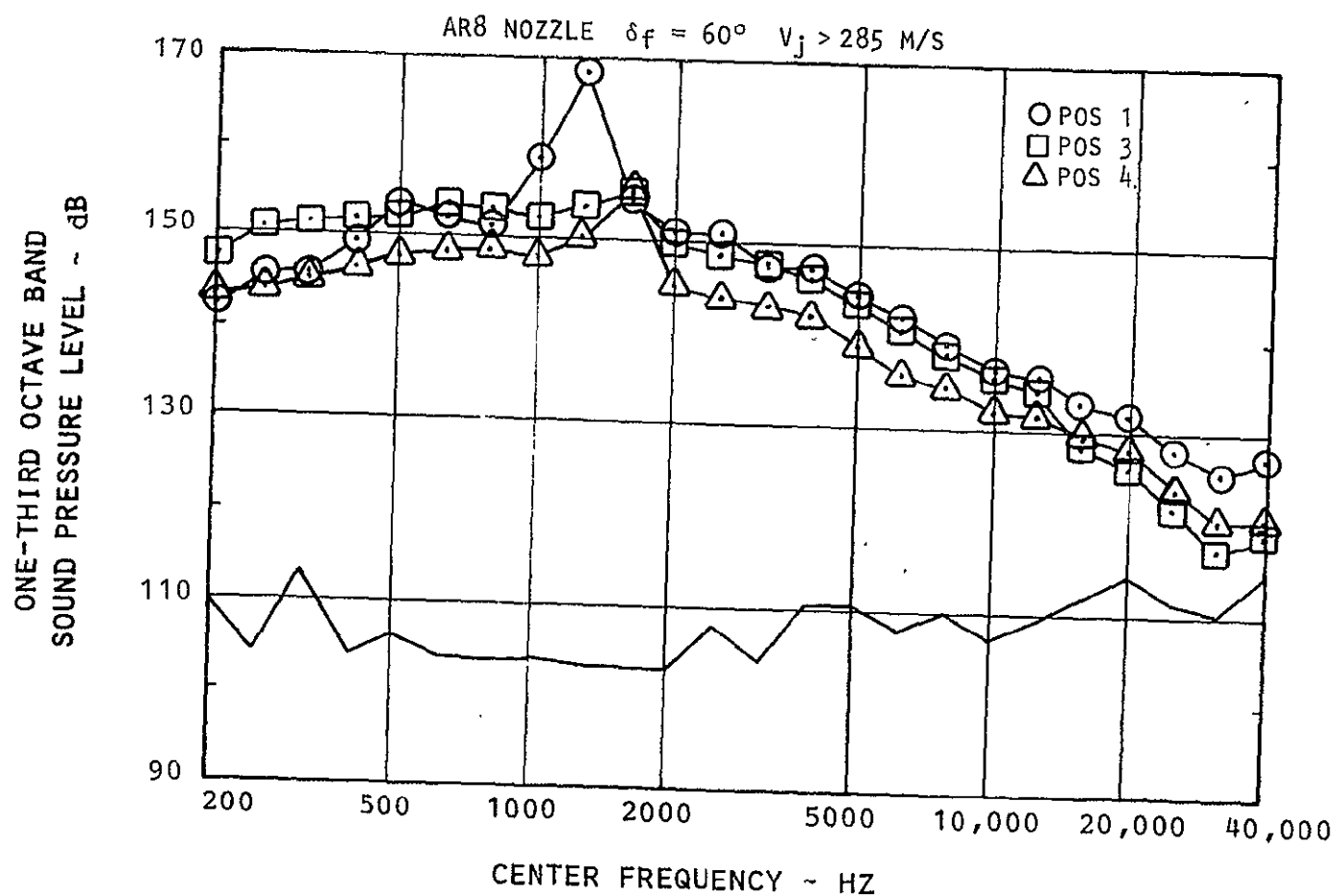


FIGURE 4-100. EFFECT OF TRANSDUCER POSITION ON
SURFACE FLUCTUATING PRESSURE

LARGE-SCALE DATA MEASURED ON FLAP SURFACE PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

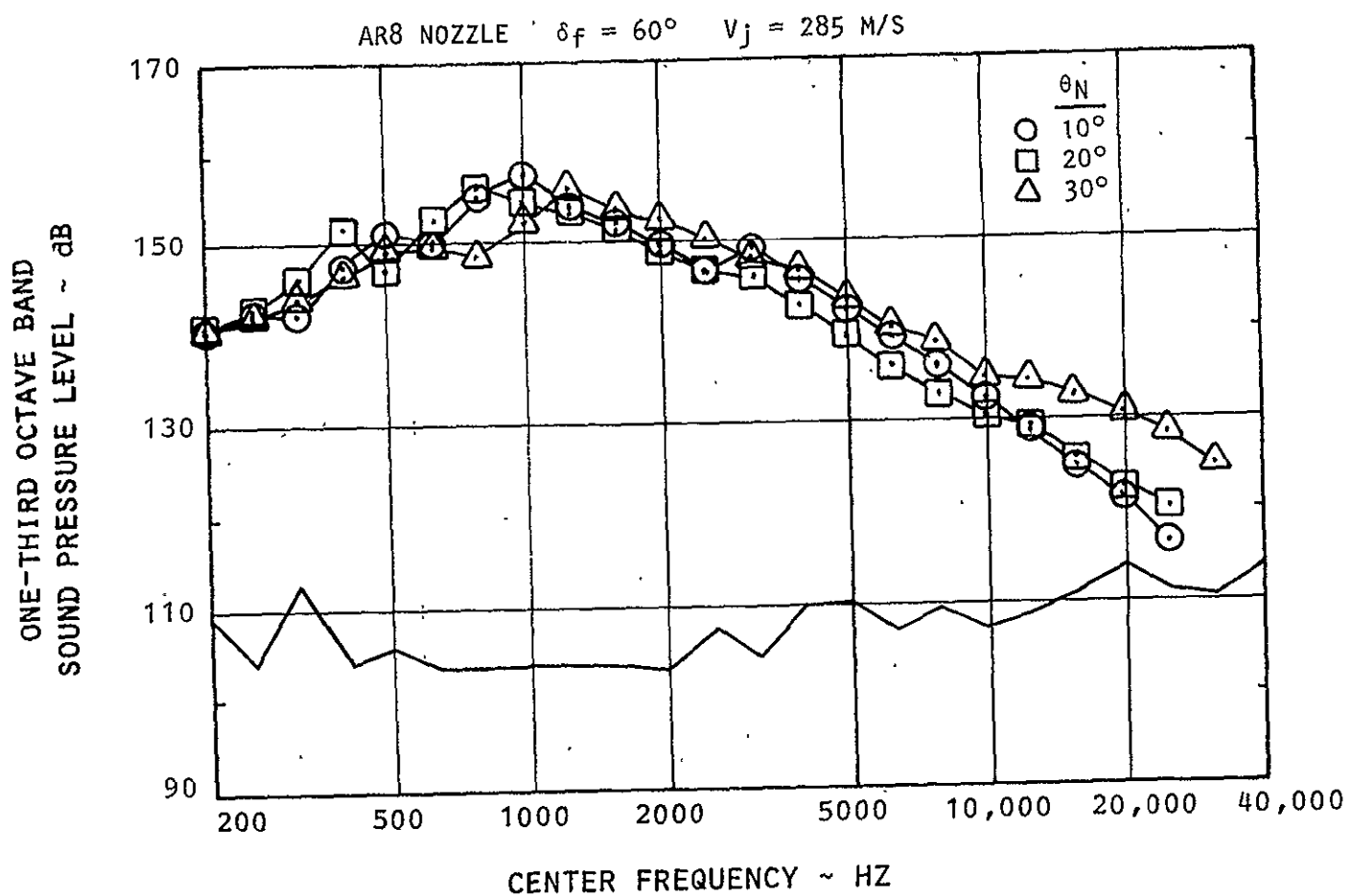
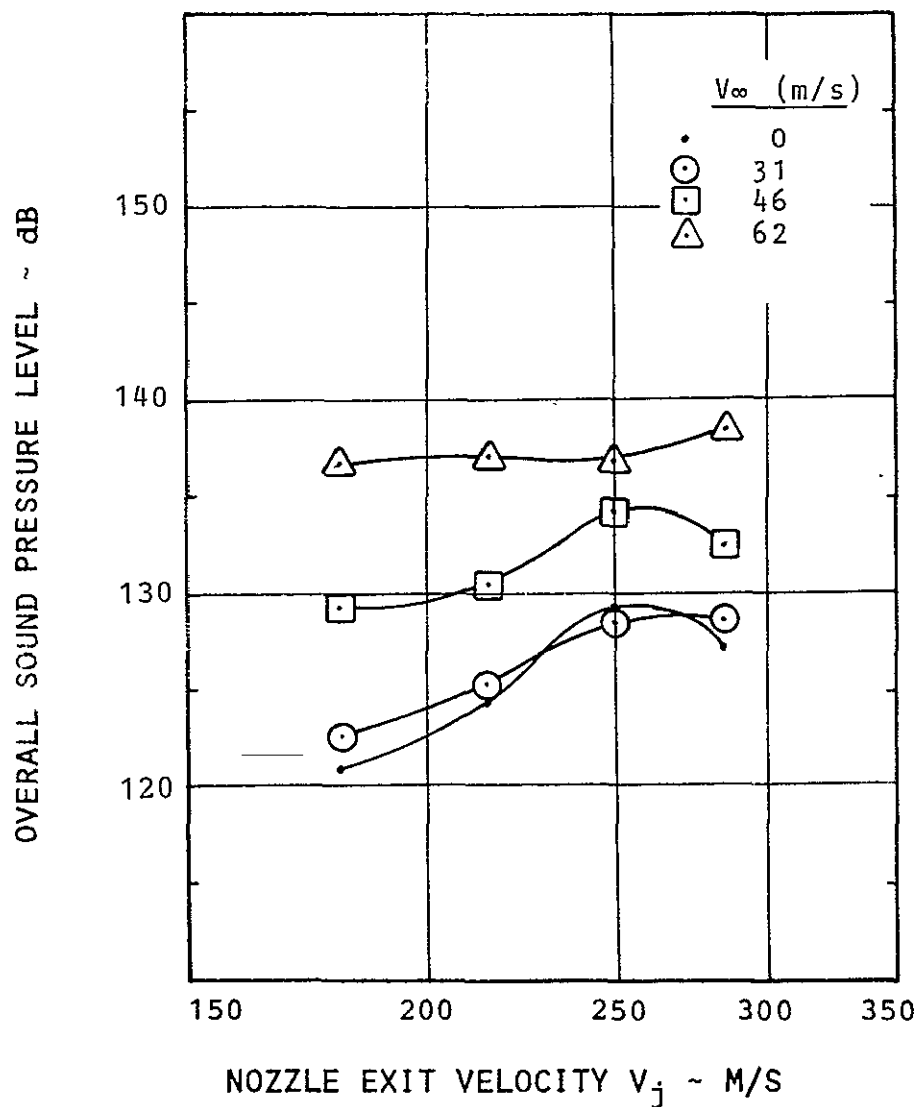


FIGURE 4-101. EFFECT OF NOZZLE INCLINATION ON SURFACE FLUCTUATING PRESSURE

SMALL SCALE MODEL DATA ON FUSELAGE SURFACE

AR2 NOZZLE

PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

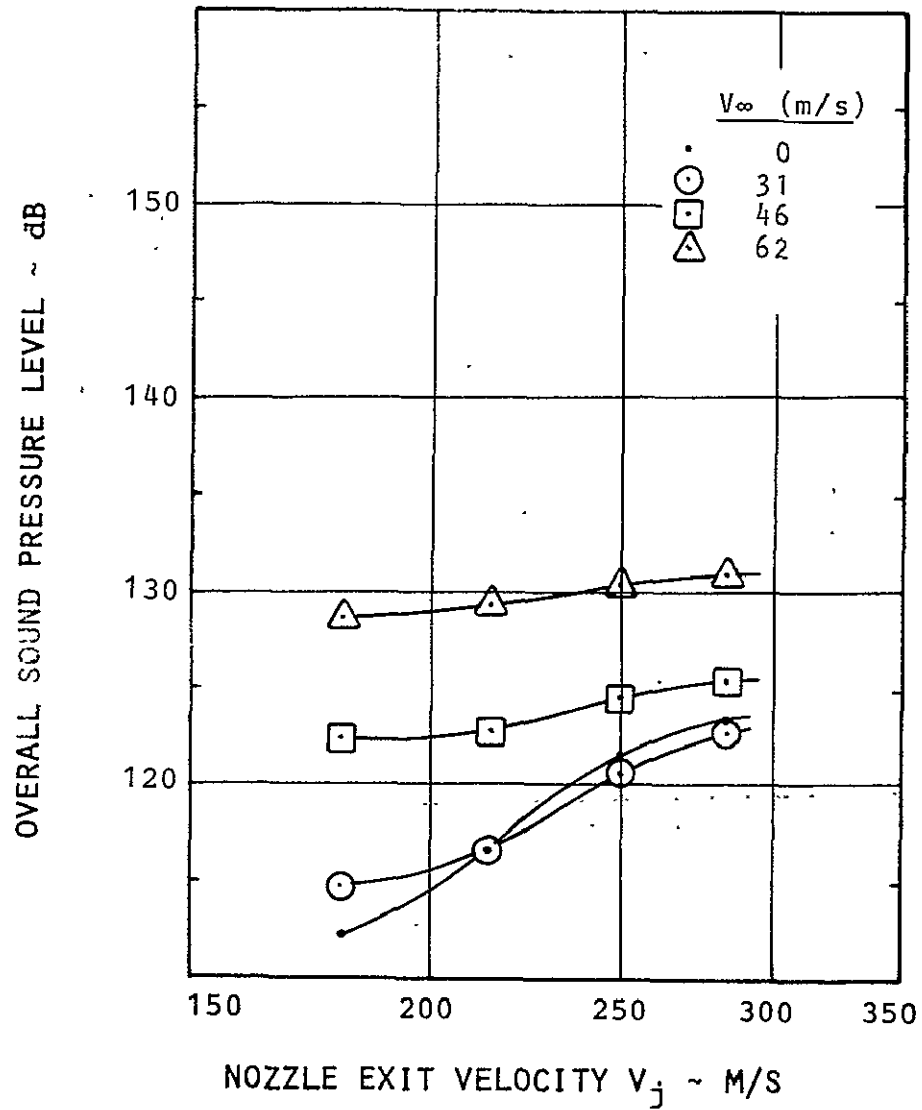


a) FORWARD MICROPHONE

FIGURE 4-102. EFFECT OF FREESTREAM VELOCITY ON OASPL

SMALL SCALE MODEL DATA ON FUSELAGE SURFACE

AR2 NOZZLE



b) CENTER MICROPHONE

FIGURE 4-102. (CONCLUDED)

SMALL SCALE MODEL DATA ON FUSELAGE SURFACE

AR2 NOZZLE

CENTER MICROPHONE

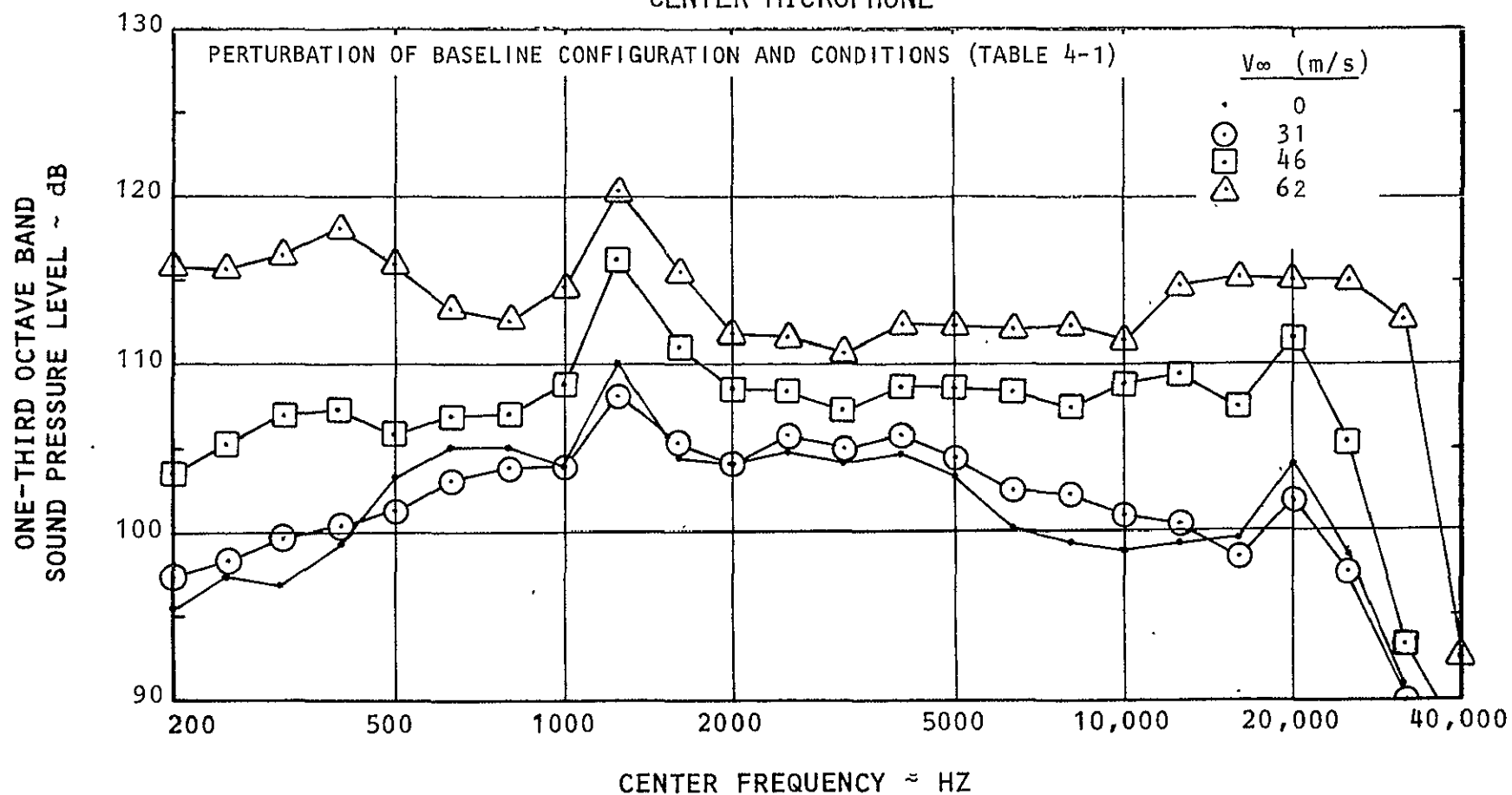


FIGURE 4-103. EFFECT OF FREESTREAM VELOCITY ON SPECTRUM

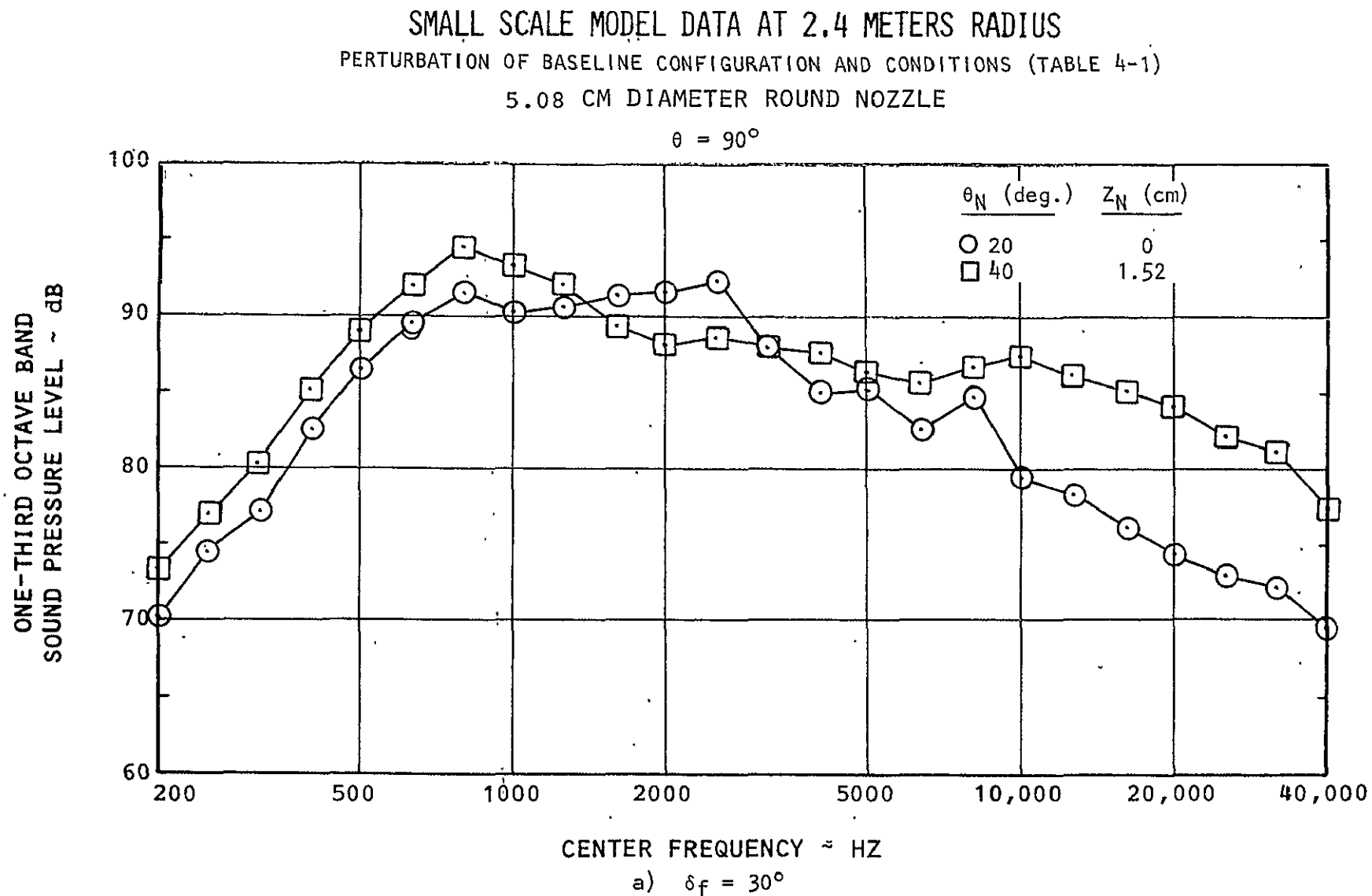


FIGURE 4-104. EFFECT OF VECTORED THRUST ON SPECTRUM - SMALL SCALE

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

5.08 CM DIAMETER ROUND NOZZLE

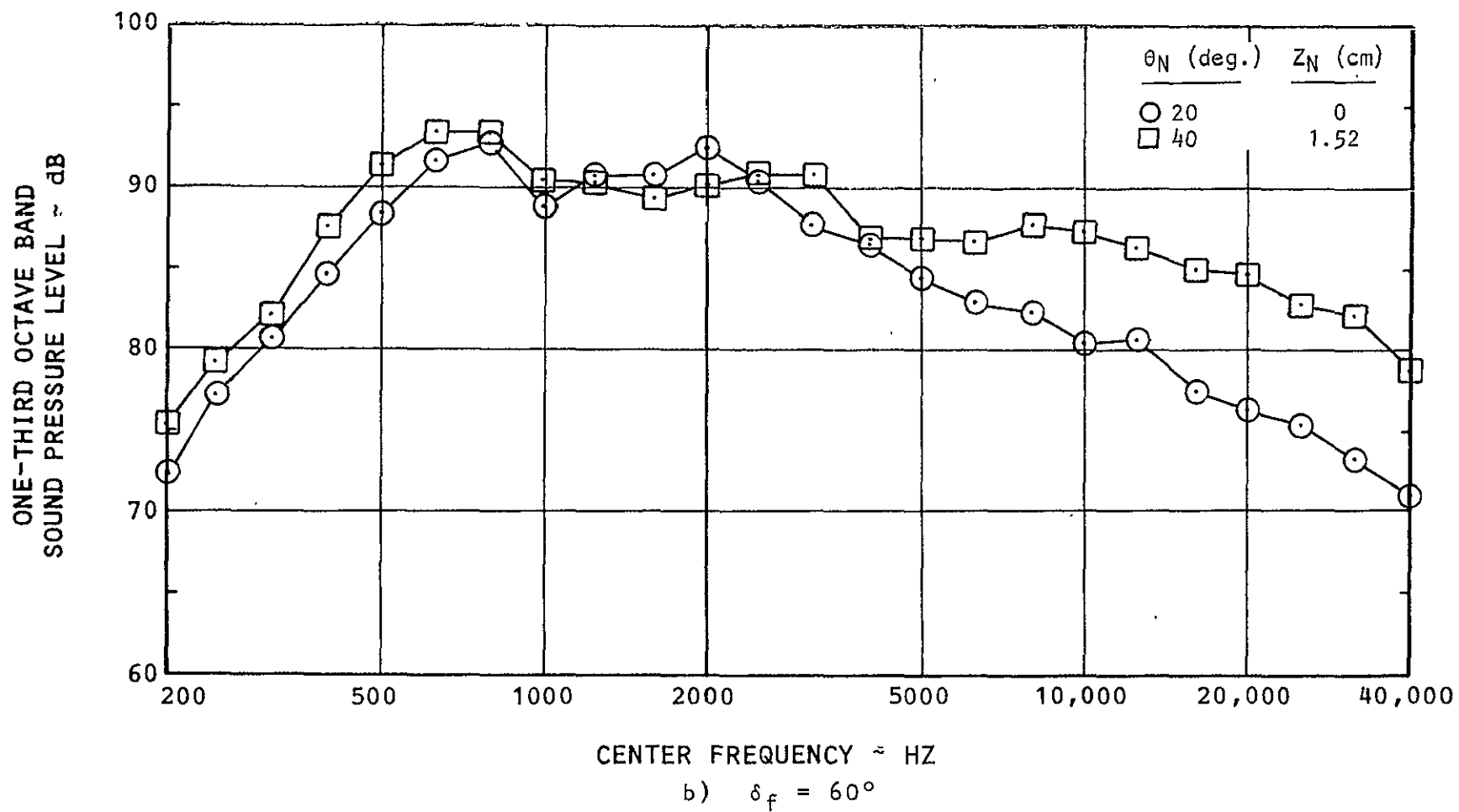


FIGURE 4-104. (CONCLUDED)

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)
 5.08 CM DIAMETER ROUND NOZZLE

$\theta = 90^\circ$

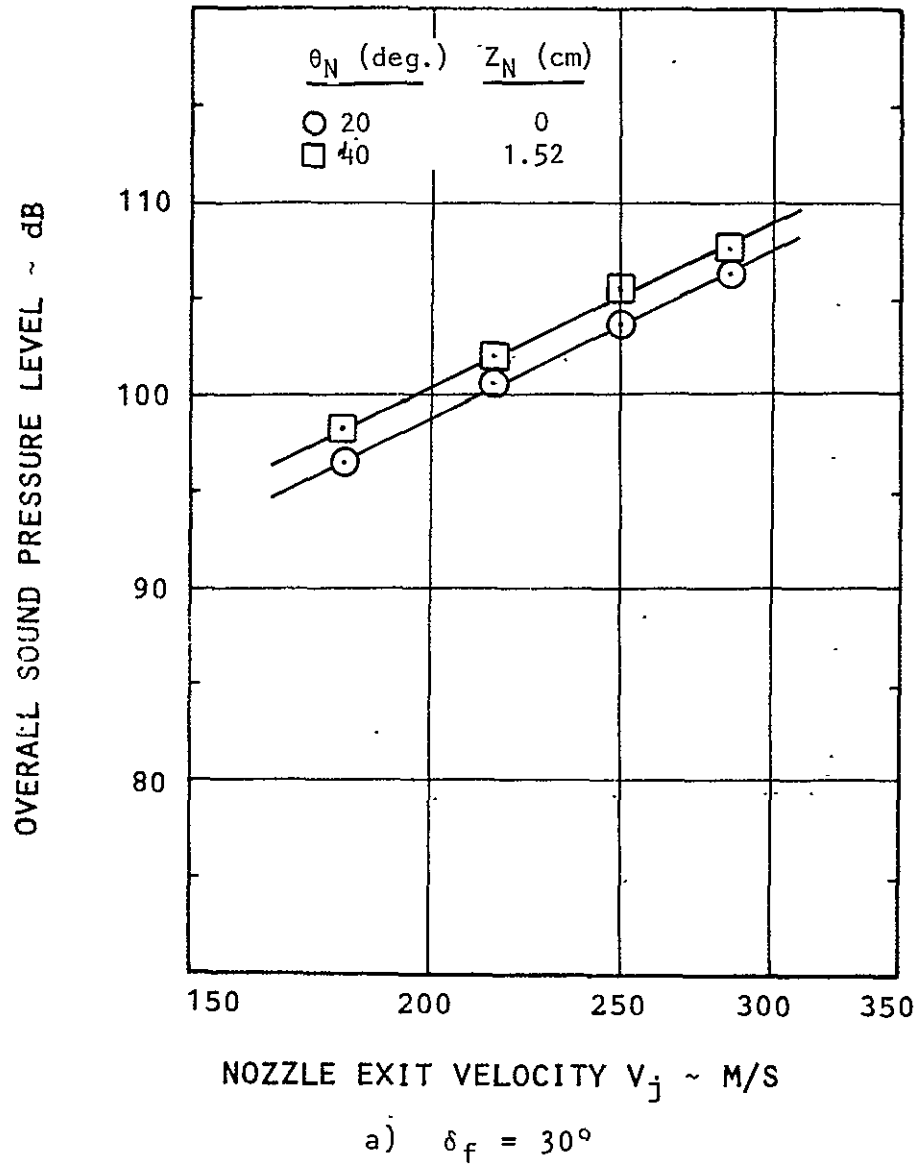
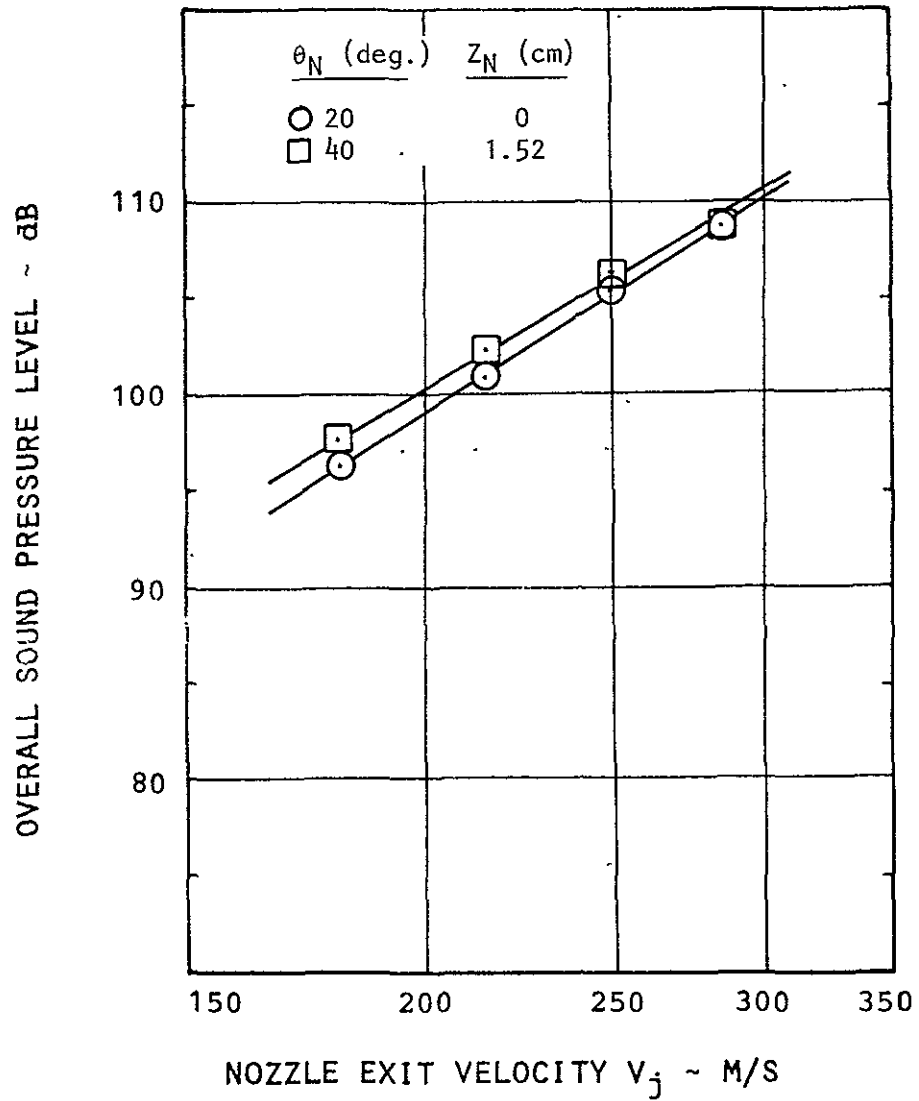


FIGURE 4-105. EFFECT OF VECTORED THRUST ON
 VELOCITY EXPONENT-SMALL SCALE

SMALL-SCALE MODEL DATA AT 2.4 METERS RADIUS

5.08 CM DIAMETER ROUND NOZZLE



b) $\delta_f = 60^\circ$

FIGURE 4-105. (CONCLUDED)

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

5.08 CM DIAMETER ROUND NOZZLE

$\delta_f = 30^\circ$

$\theta = 90^\circ$

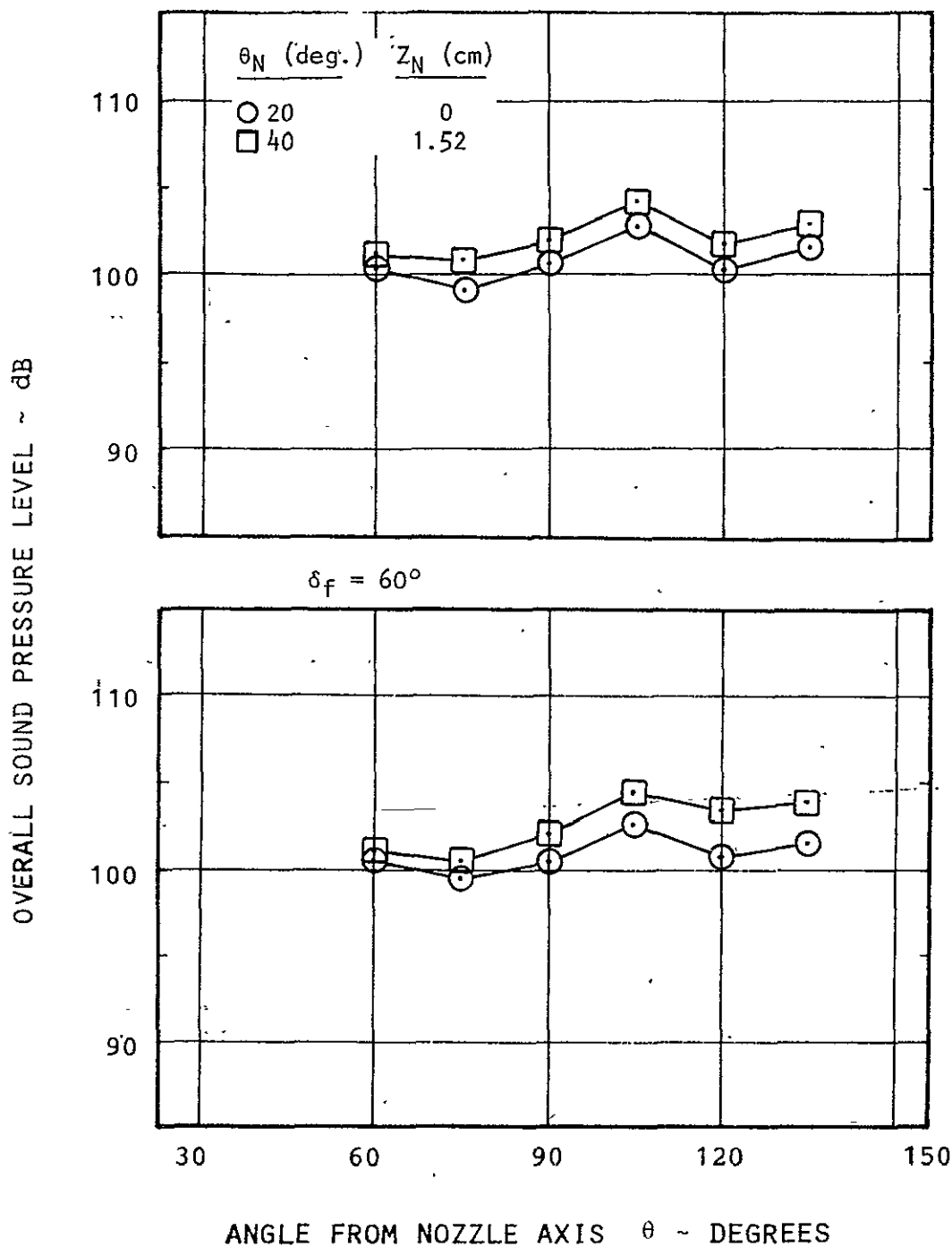


FIGURE 4-106. EFFECT OF VECTORED THRUST ON DIRECTIVITY - SMALL SCALE

LARGE SCALE MODEL DATA AT 6.1 METERS RADIUS
PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)
17.6 CM DIAMETER ROUND NOZZLE

$\theta = 90^\circ$

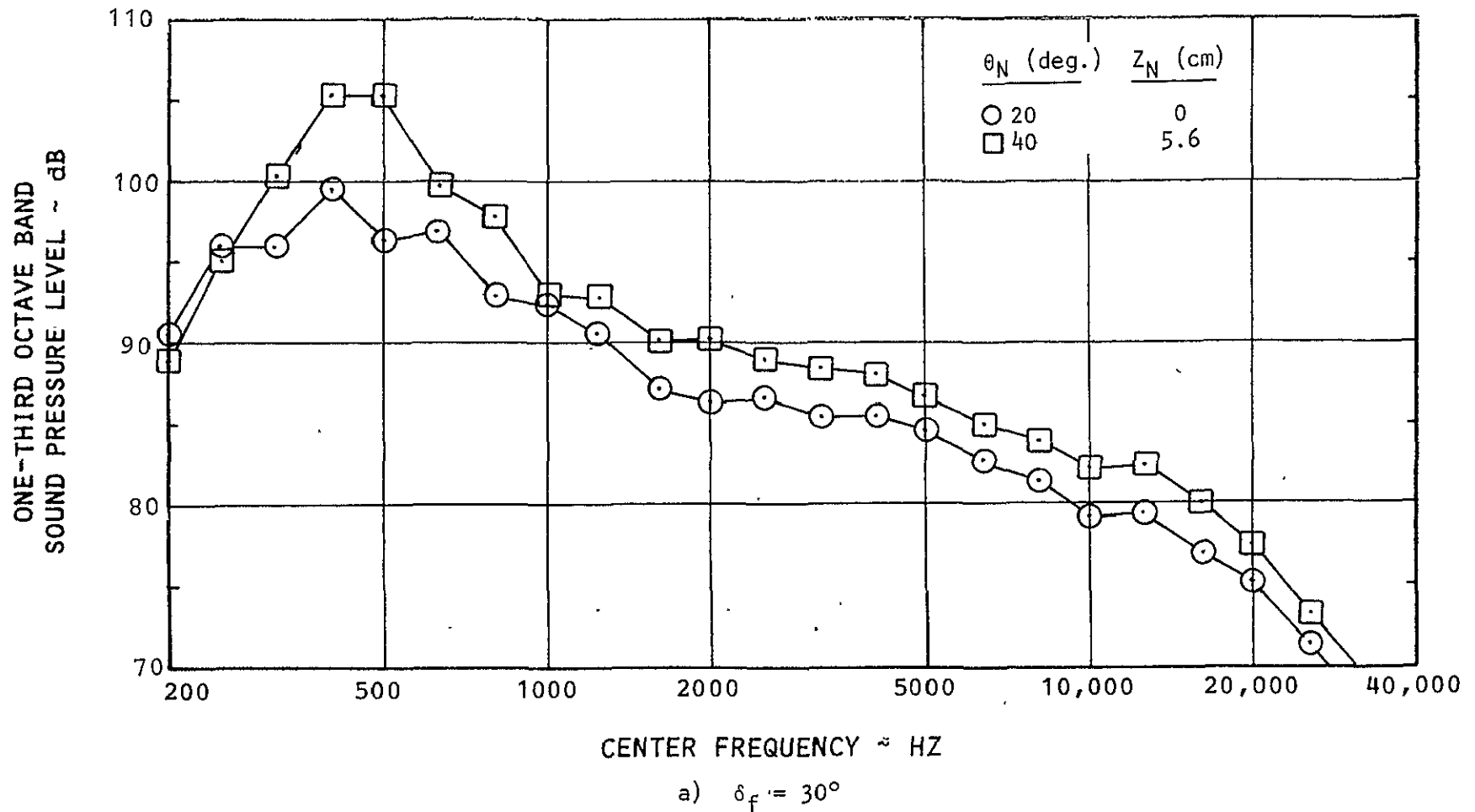


FIGURE 4-107. EFFECT OF VECTORED THRUST ON SPECTRUM - LARGE SCALE

LARGE SCALE MODEL DATA AT 6.1 METERS RADIUS

17.6 CM DIAMETER ROUND NOZZLE

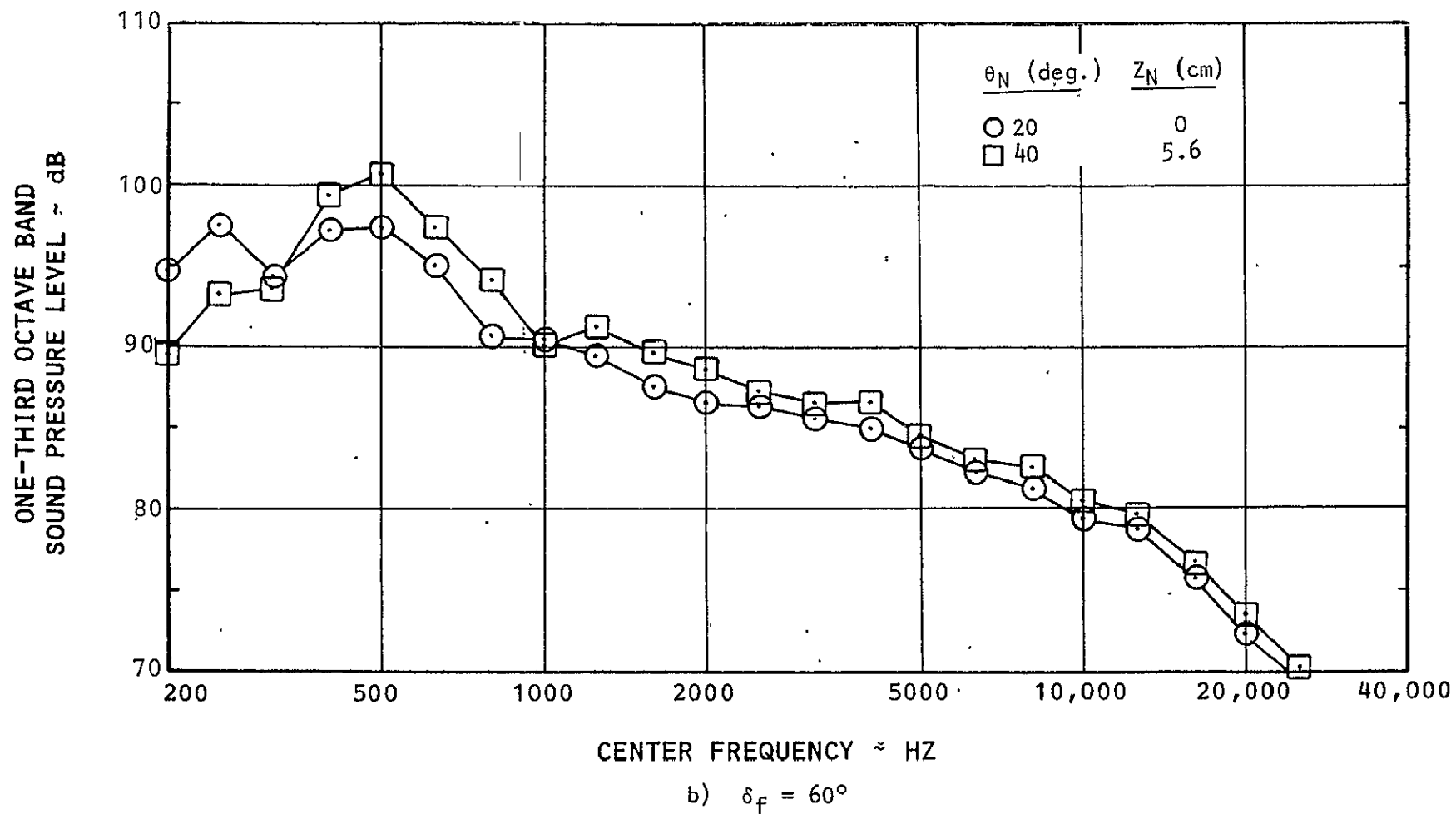


FIGURE 4-107. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS
 PERTURBATION OF BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)
 17.6 CM DIAMETER ROUND NOZZLE
 $\delta_f = 30^\circ$

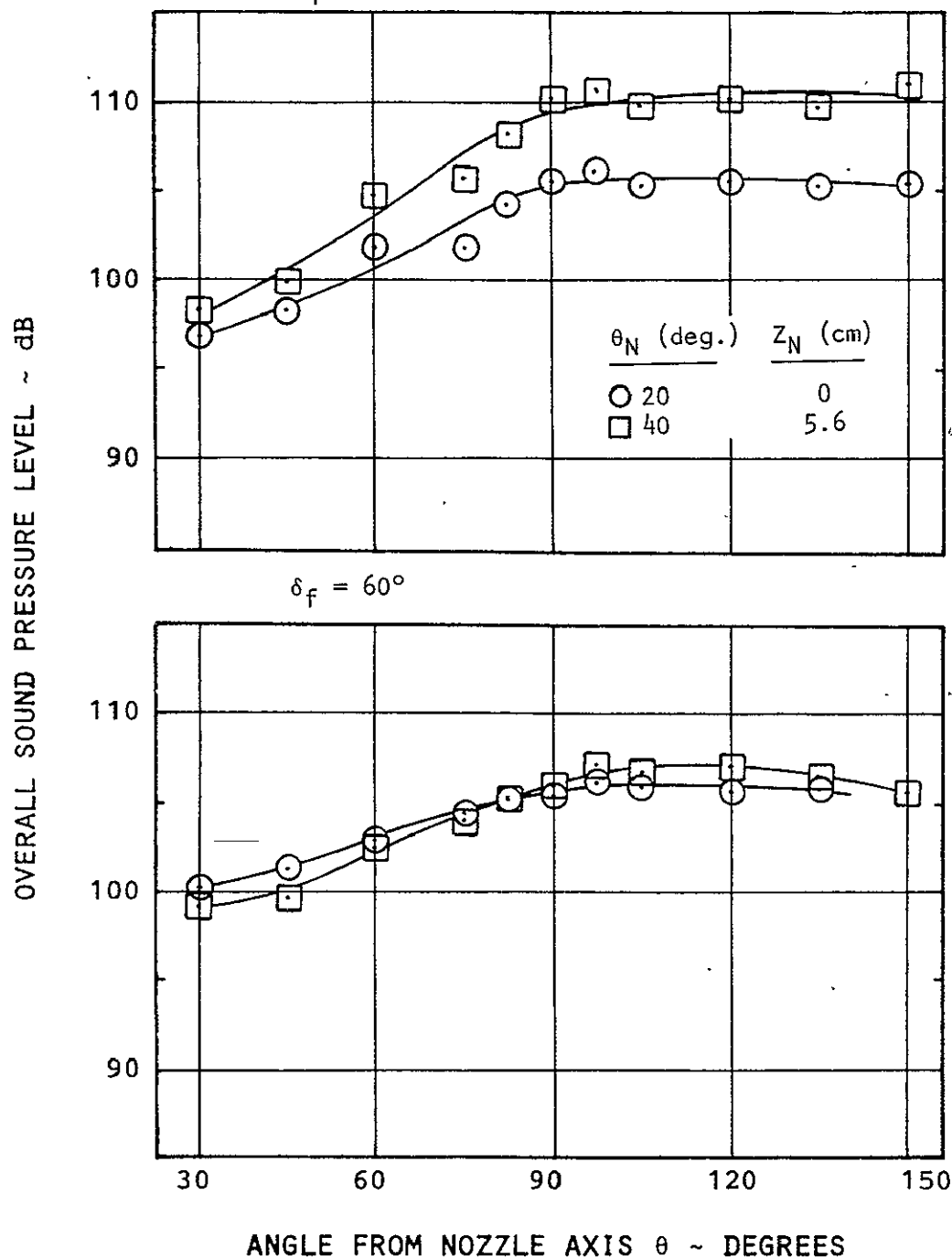


FIGURE 4-108. EFFECT OF VECTORED THRUST ON
 DIRECTIVITY - LARGE SCALE

SMALL SCALE DATA AT 2.4 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

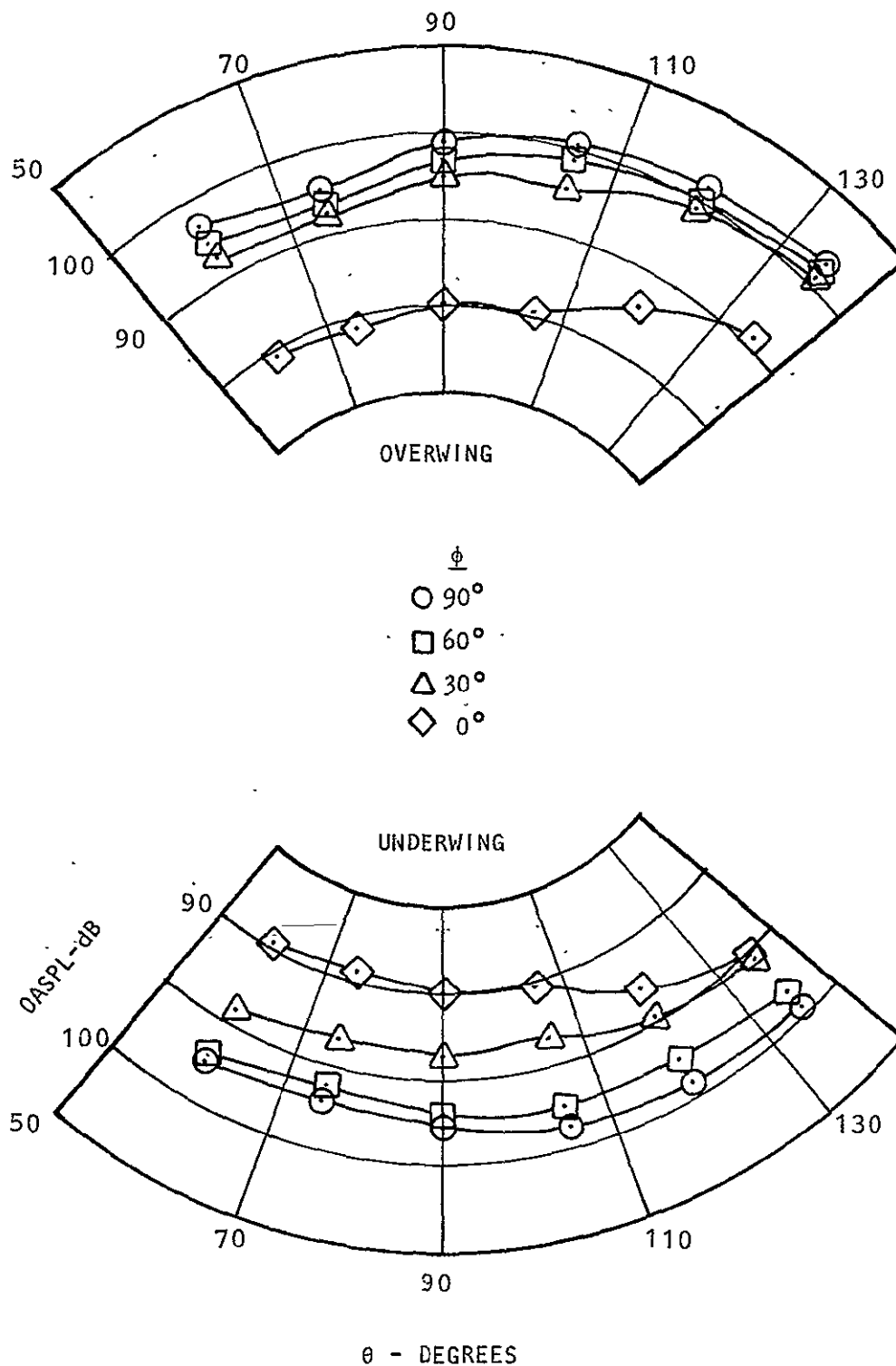


FIGURE 4-109. OASPL DIRECTIVITIES IN θ -PLANE - SMALL SCALE

SMALL SCALE DATA AT 2.4 METERS RADIUS BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

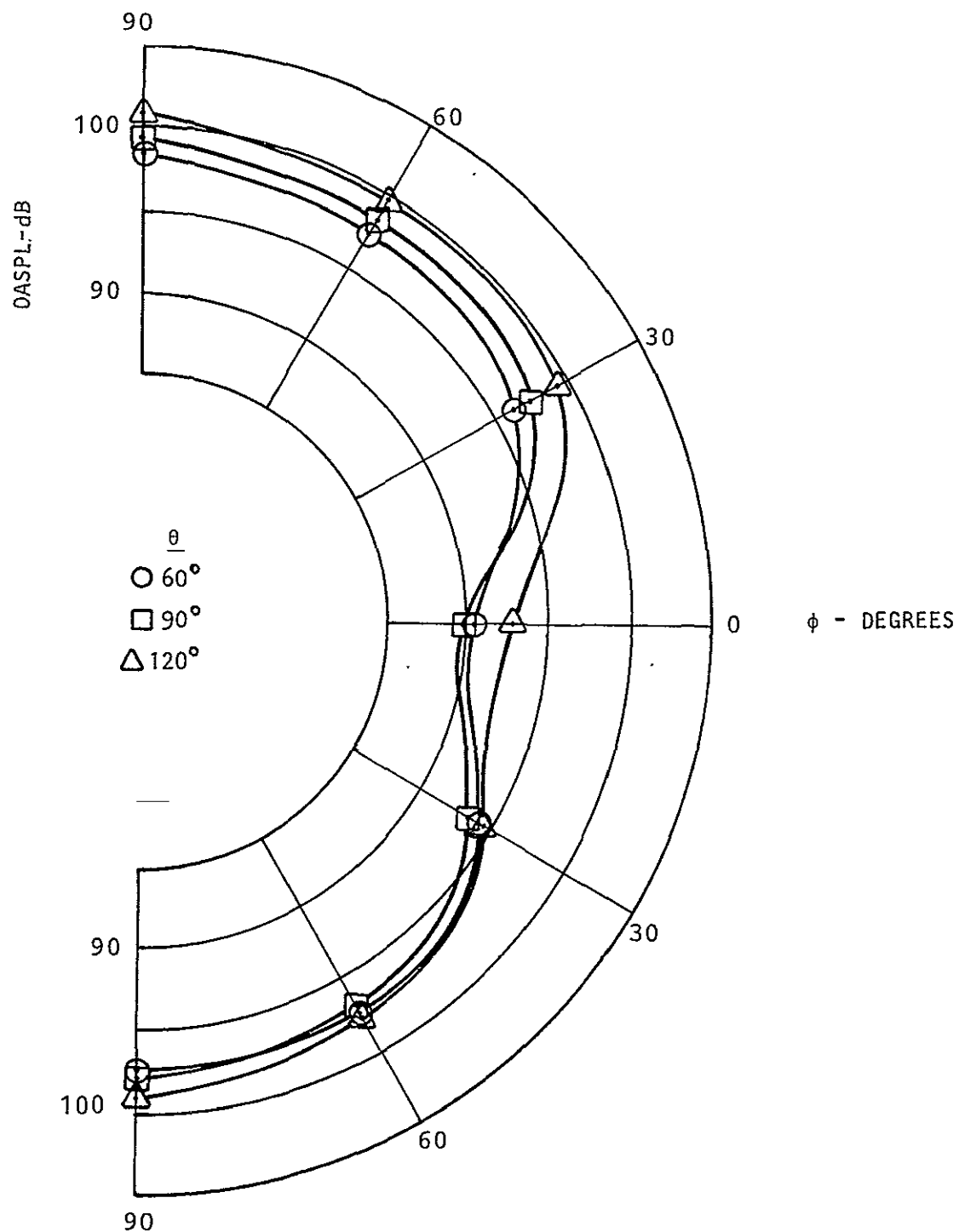


FIGURE 4-110. OASPL DIRECTIVITIES IN ϕ -PLANE - SMALL SCALE

LARGE SCALE DATA AT 6.1 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

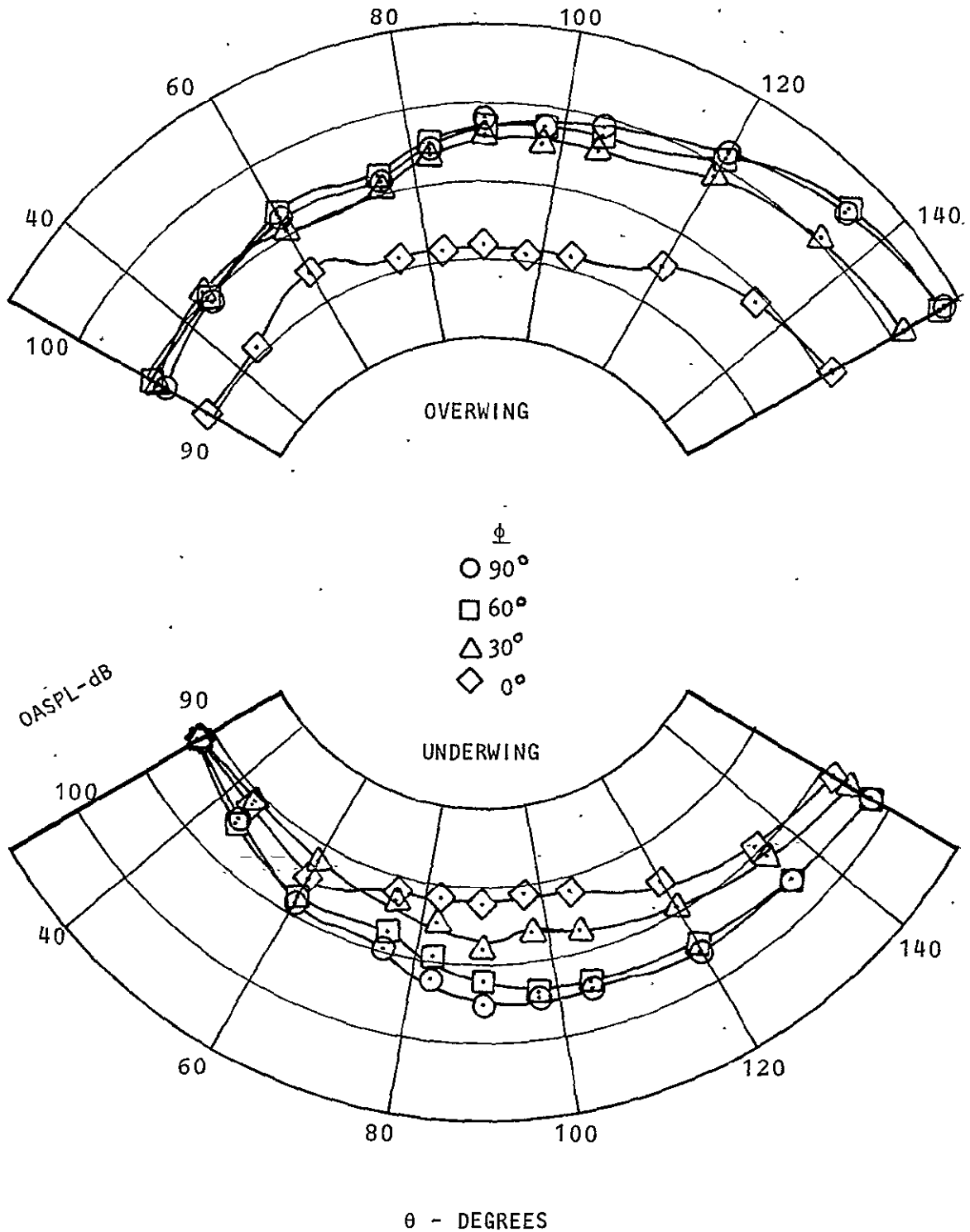


FIGURE 4-111. OASPL DIRECTIVITIES IN θ -PLANE - LARGE SCALE

LARGE-SCALE DATA AT 6.1 METERS RADIUS
 BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

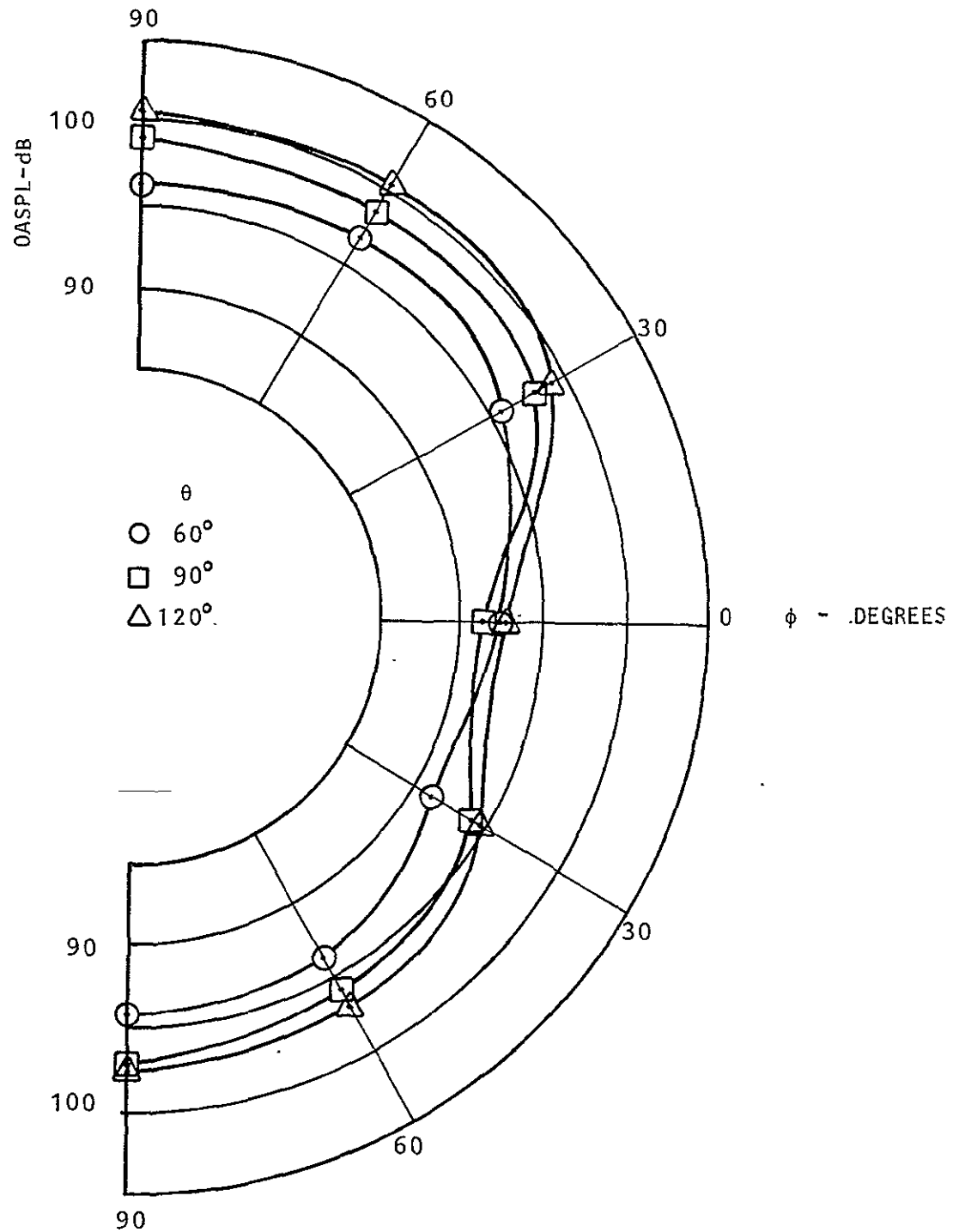


FIGURE 4-112. OASPL DIRECTIVITIES IN ϕ -PLANE - LARGE SCALE

SMALL SCALE MODEL DATA AT 2.4 METERS RADIUS

BASELINE CONFIGURATION AND CONDITIONS (TABLE 4-1)

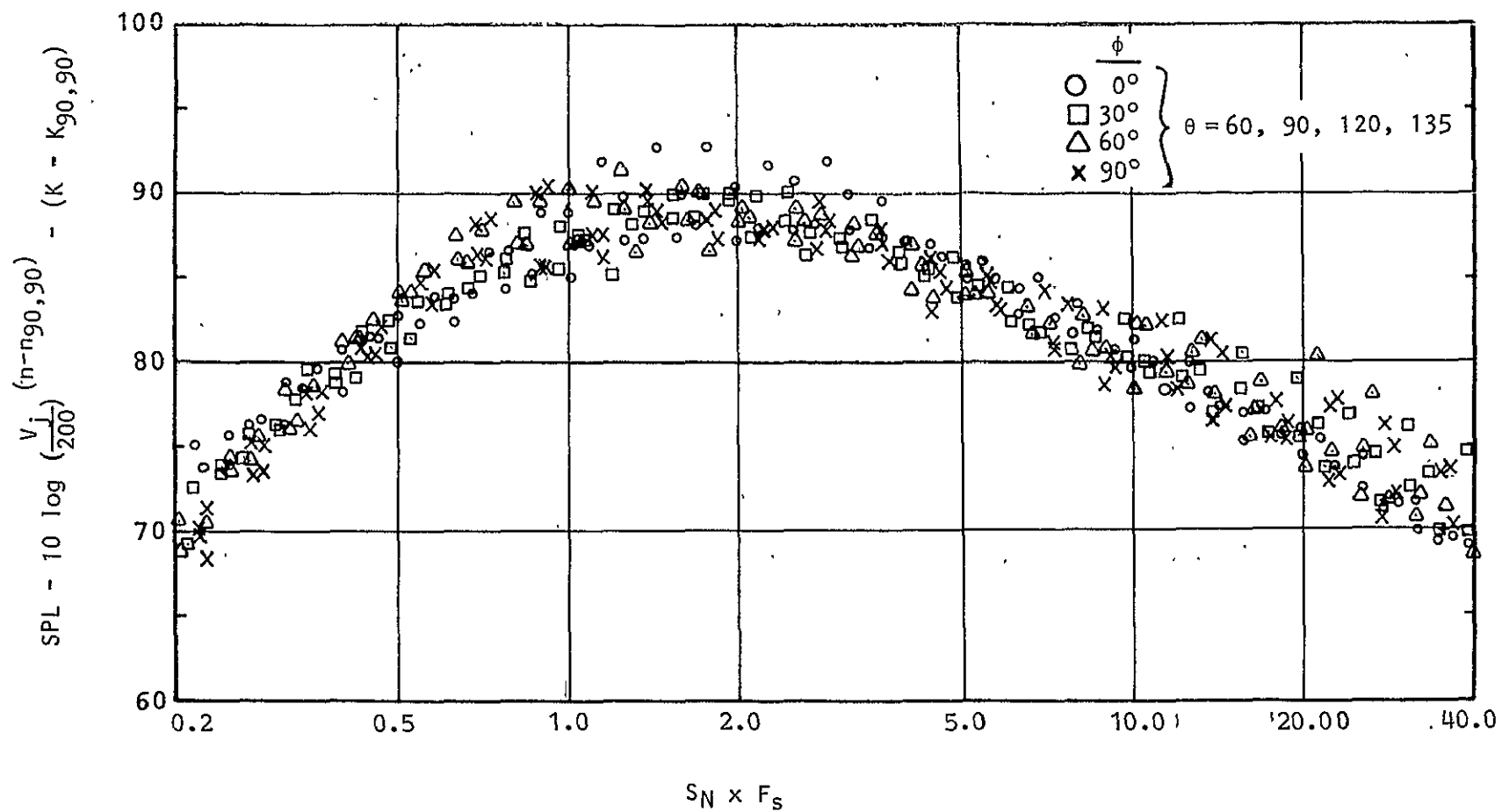


FIGURE 4-113. SPECTRUM DIRECTIVITY NORMALIZATION

APPLICABILITY:

NOZZLE SHAPE

RECTANGULAR (AR = 2, 4, 8)
CIRCULAR, ELLIPTICAL, D

FLAP DEFLECTION

30° TO 60°

NOZZLE IMPINGEMENT ANGLE

APPROX. 20°

NOZZLE CHORDWISE POSITION

$X_N/C = 0.20$ TO 0.50

NOZZLE VERTICAL POSITION

$Z_N = 0.0$

FLOW LENGTH/NOZ. HYDRAULIC DIA.

9.3 TO 3.2

JET TEMPERATURE

AMBIENT

JET VELOCITY

180 TO 285 M/S

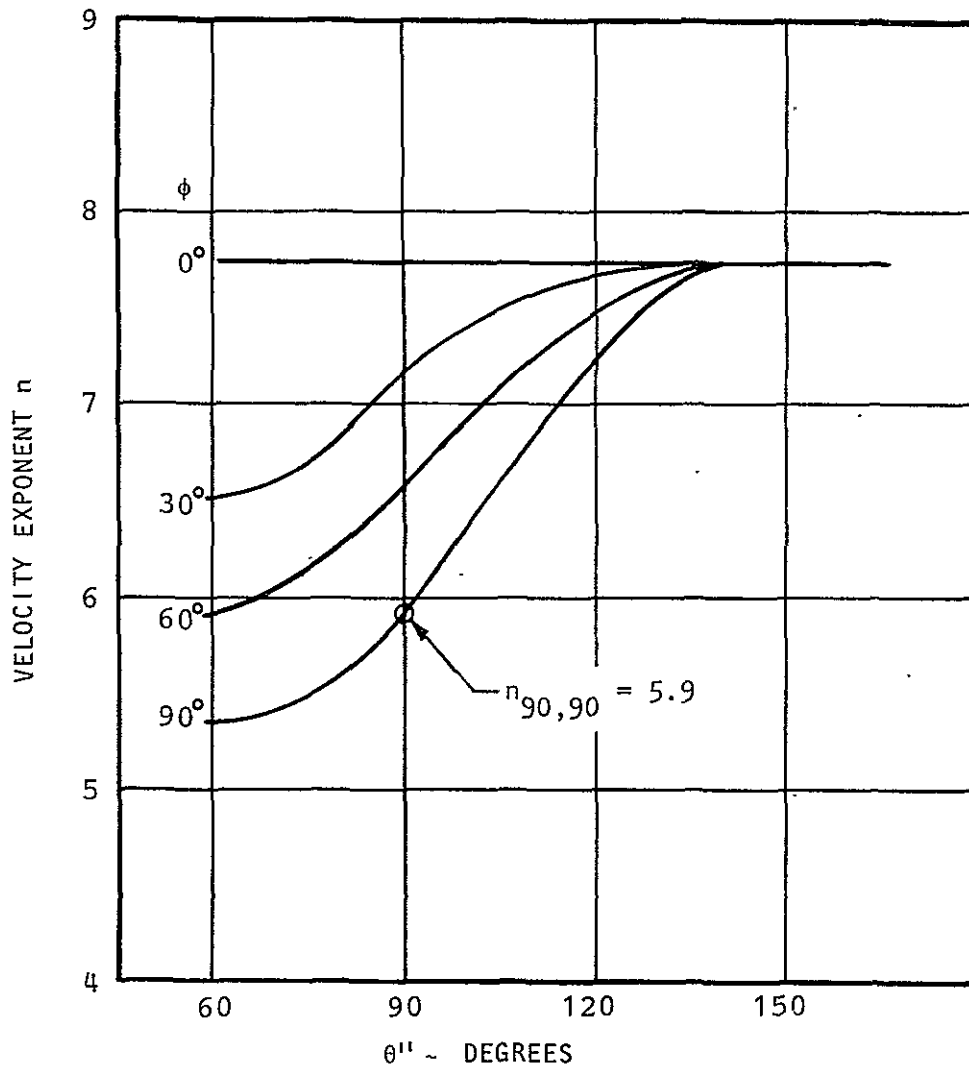


FIGURE 4-114. VARIATION OF VELOCITY EXPONENT n WITH MICROPHONE POSITION

APPLICABILITY:

NOZZLE SHAPE

RECTANGULAR (AR = 2, 4, 8)
CIRCULAR, ELLIPTICAL, D

FLAP DEFLECTION

30° TO 60°
APPROX. 20°

NOZZLE IMPINGEMENT ANGLE

$X_N/C = 0.20$ TO 0.50

NOZZLE CHORDWISE POSITION

$Z_N = 0.0$

NOZZLE VERTICAL POSITION

9.3 TO 3.2

FLOW LENGTH/NOZ. HYDRAULIC DIA.

JET TEMPERATURE

AMBIENT

JET VELOCITY

180 TO 285 M/S

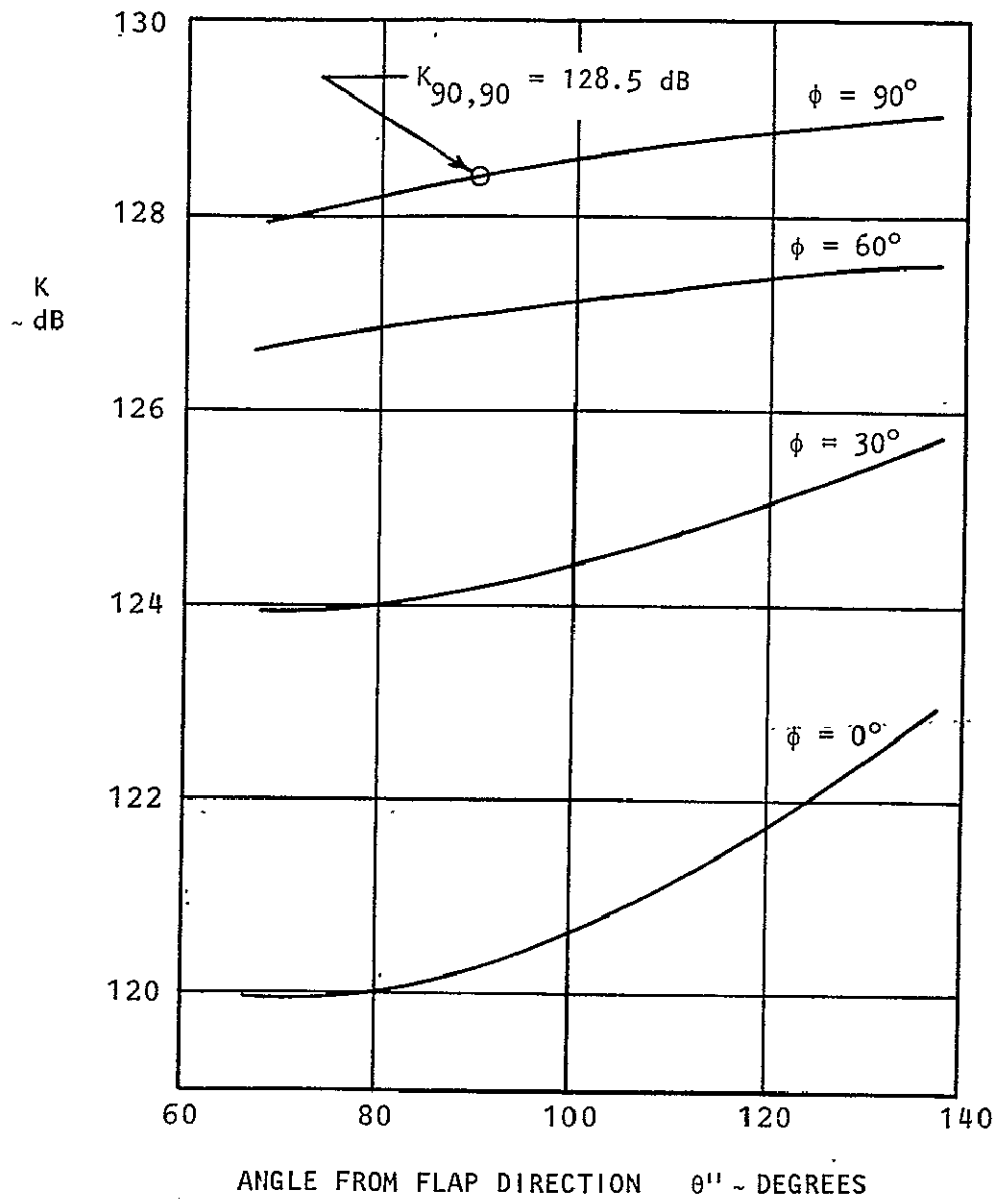


FIGURE 4-115. SPECTRUM DIRECTIVITY FACTOR K

APPLICABILITY:

NOZZLE SHAPE

RECTANGULAR (AR = 2, 4, 8)
CIRCULAR, ELLIPTICAL, D

FLAP DEFLECTION

30° TO 60°

NOZZLE IMPINGEMENT ANGLE

APPROX. 20°

NOZZLE CHORDWISE POSITION

$X_N/C = 0.20$ TO 0.50

NOZZLE VERTICAL POSITION

$Z_N = 0.0$

FLOW LENGTH/NOZ. HYDRAULIC DIA.

9.3 TO 3.2

JET TEMPERATURE

AMBIENT

JET VELOCITY

180 TO 285 M/S

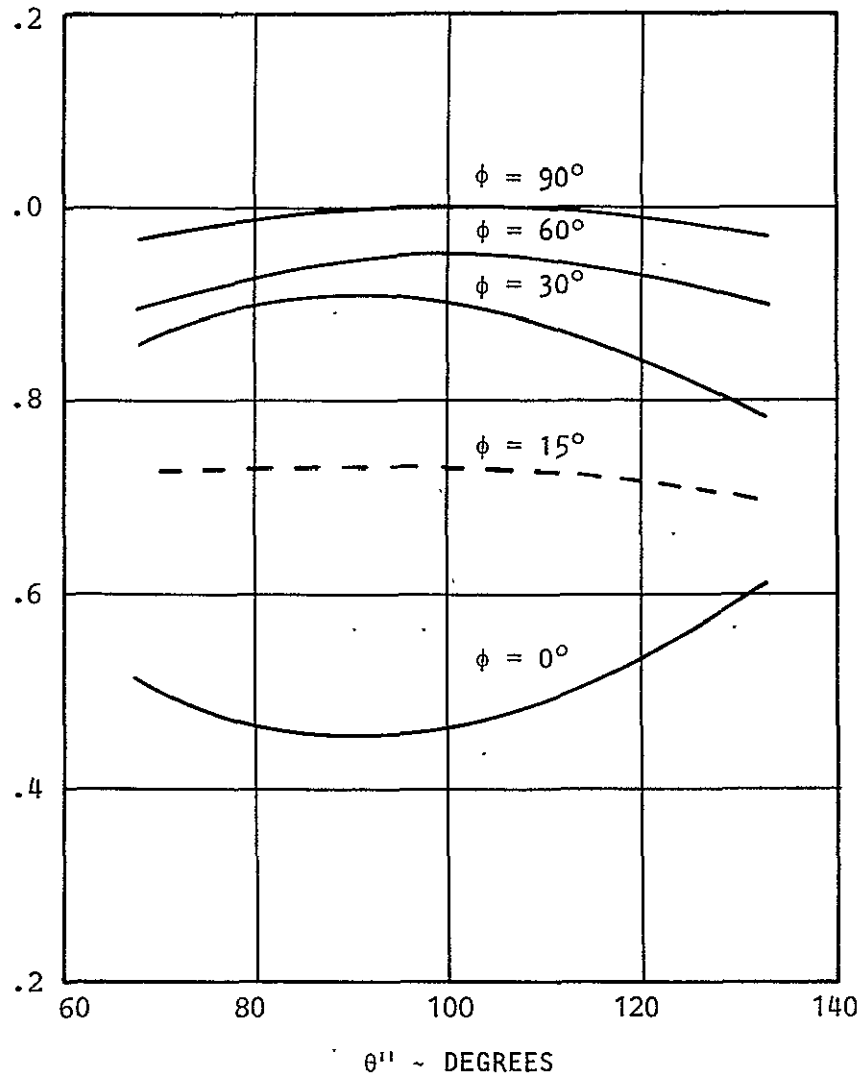


FIGURE 4-116. STROUHAL NUMBER CORRECTION FACTOR

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR4 NOZZLE ALONE

$V_J = 215 \text{ M/S}$

$\theta = 90^\circ$

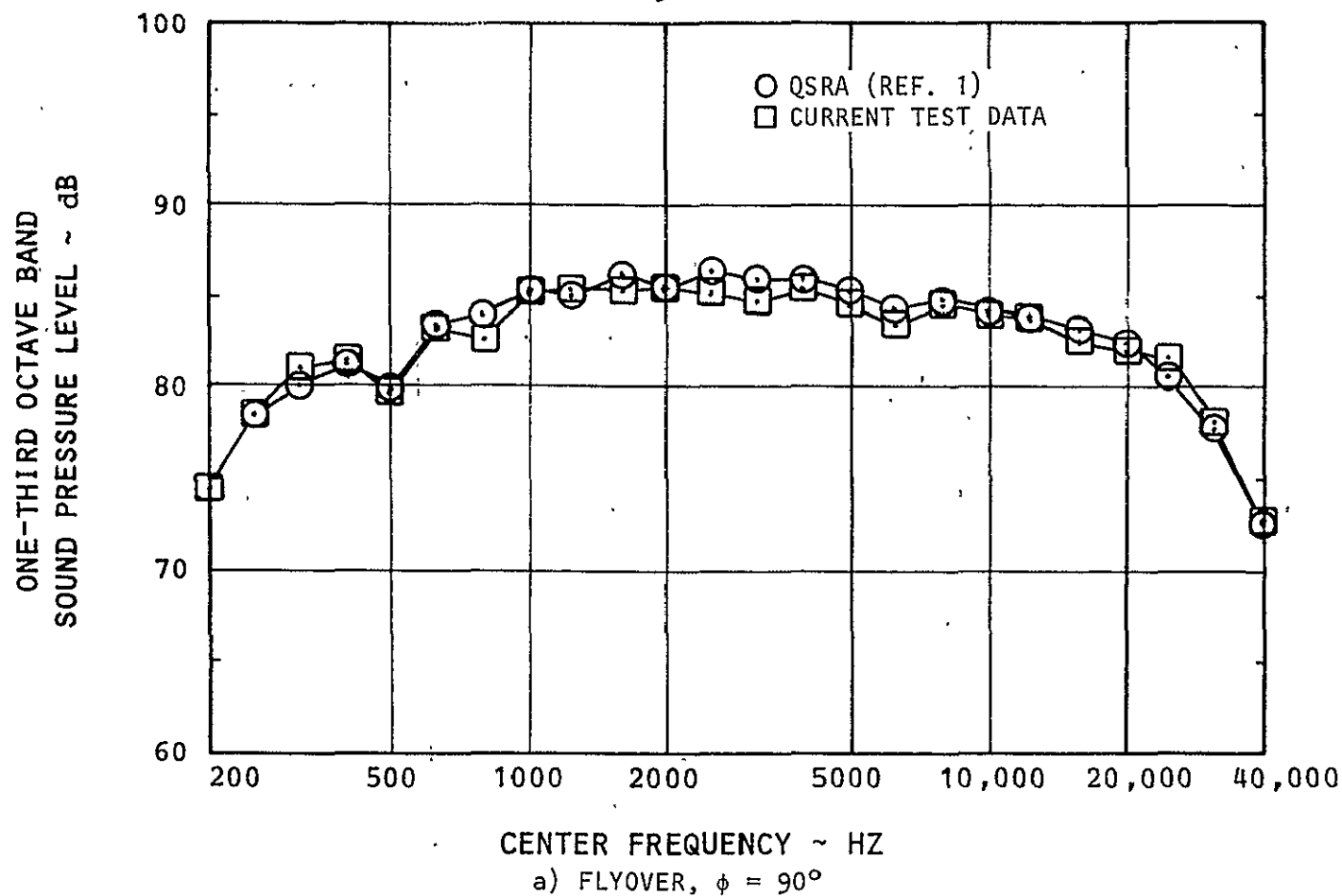
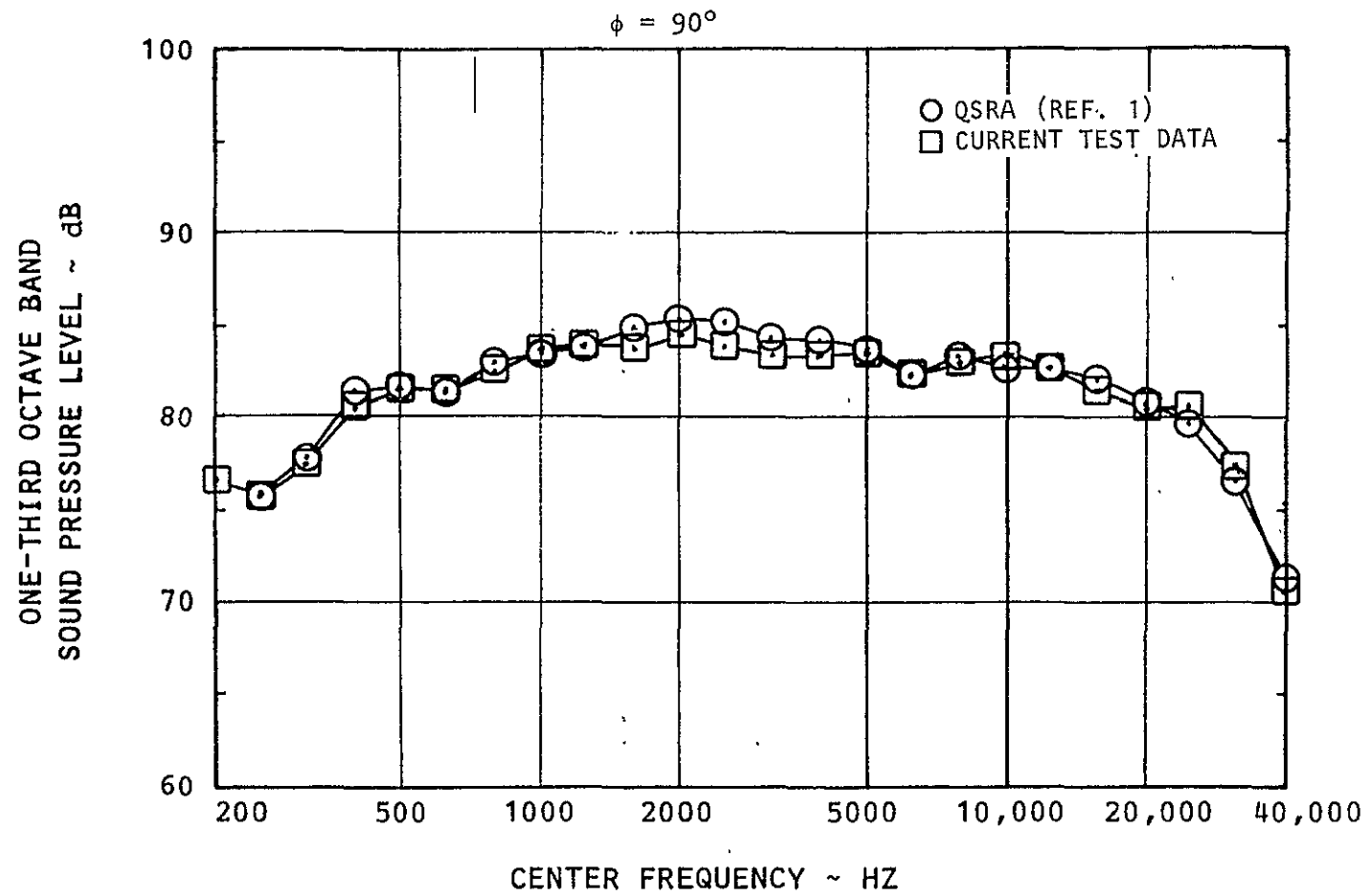


FIGURE 4-117. COMPARISON OF SPECTRA WITH EARLIER TEST DATA

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR4 NOZZLE ALONE



b) SIDELINE, $\phi = 30^\circ$

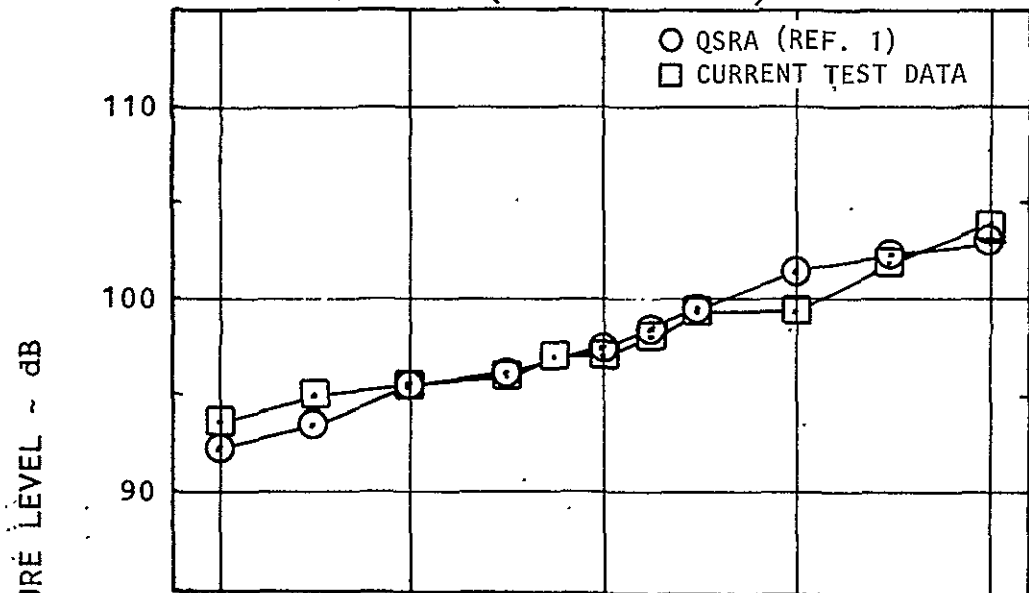
FIGURE 4-117. (CONCLUDED)

LARGE-SCALE MODEL DATA AT 6.1 METERS RADIUS

AR4 NOZZLE ALONE

$V_J = 215 \text{ M/S}$

$\phi = 90^\circ$ (FLYOVER PLANE)



$\phi = 30^\circ$

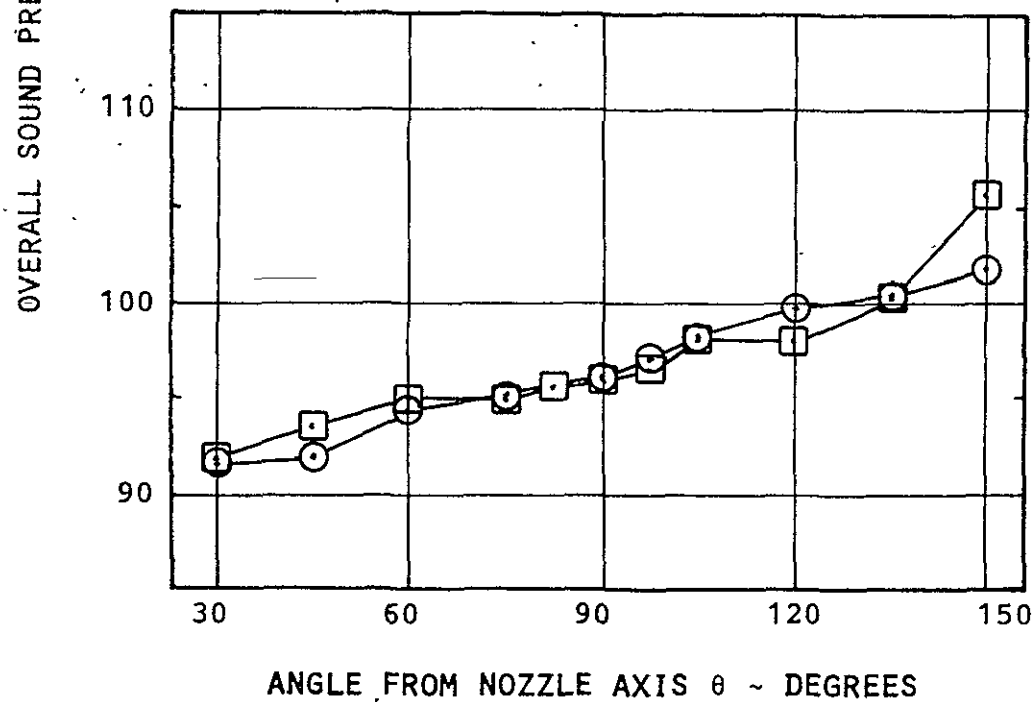


FIGURE 4-118. COMPARISON OF DIRECTIVITIES WITH EARLIER TEST DATA

DATA SCALED TO 114 CM² NOZZLE AREA AND 6.1 METERS RADIUS

$\delta_f = 60^\circ$, $V_j = 215$ M/S, $\phi = 90^\circ$, $\theta = 90^\circ$ TO 120°

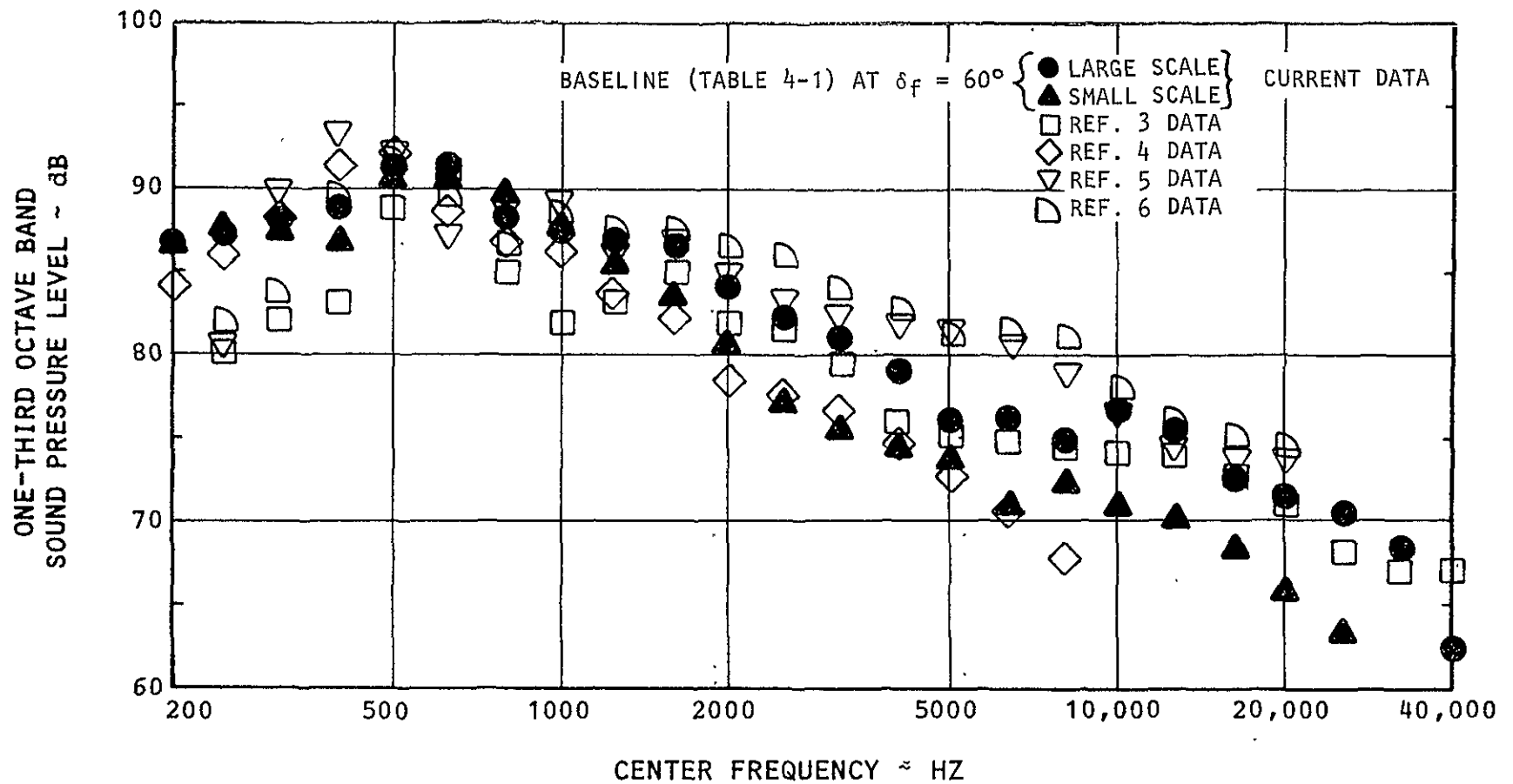


FIGURE 4-119. COMPARISON WITH OTHER DATA — ONE-THIRD OCTAVE BAND SPECTRA.

DATA SCALED TO 114 CM² NOZZLE AREA AND 6.1 METERS RADIUS

$\delta_f \approx 60^\circ$, $\phi = 90^\circ$, $\theta = 90^\circ$ TO 120°

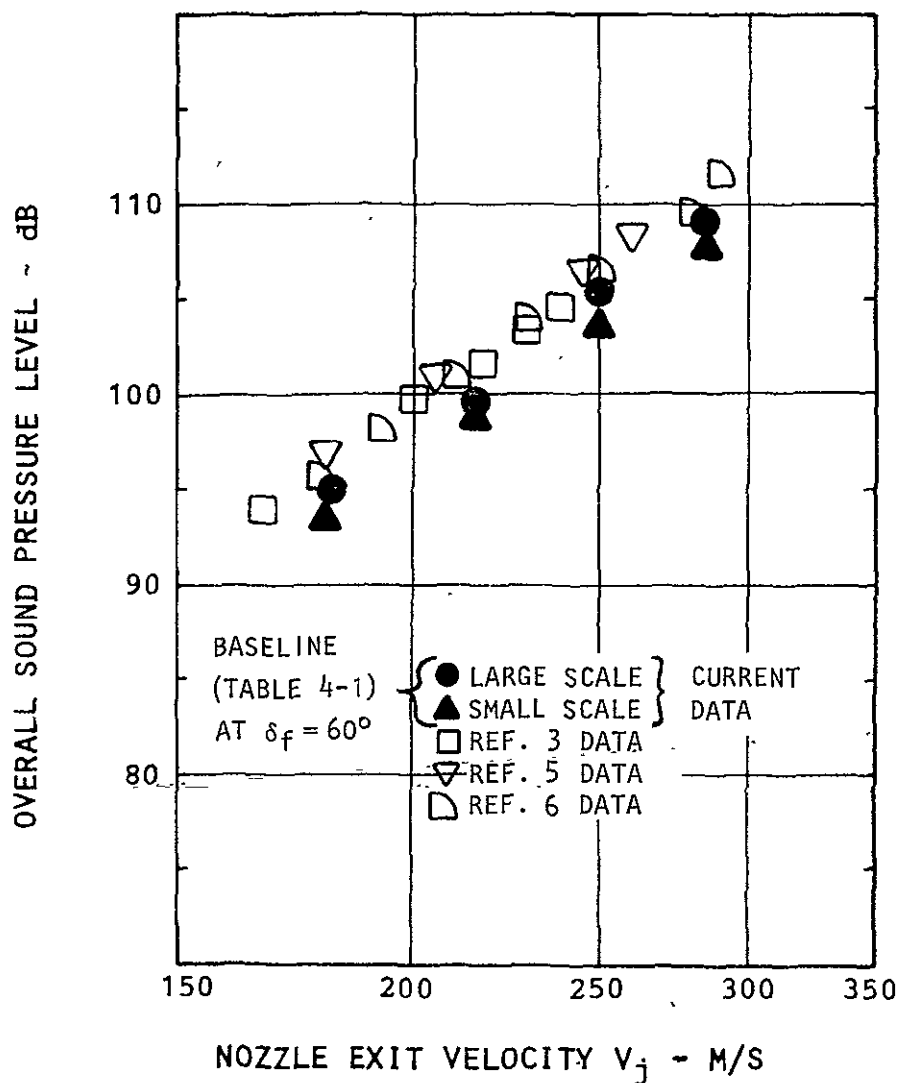


FIGURE 4-120. COMPARISON WITH OTHER DATA - OASPL

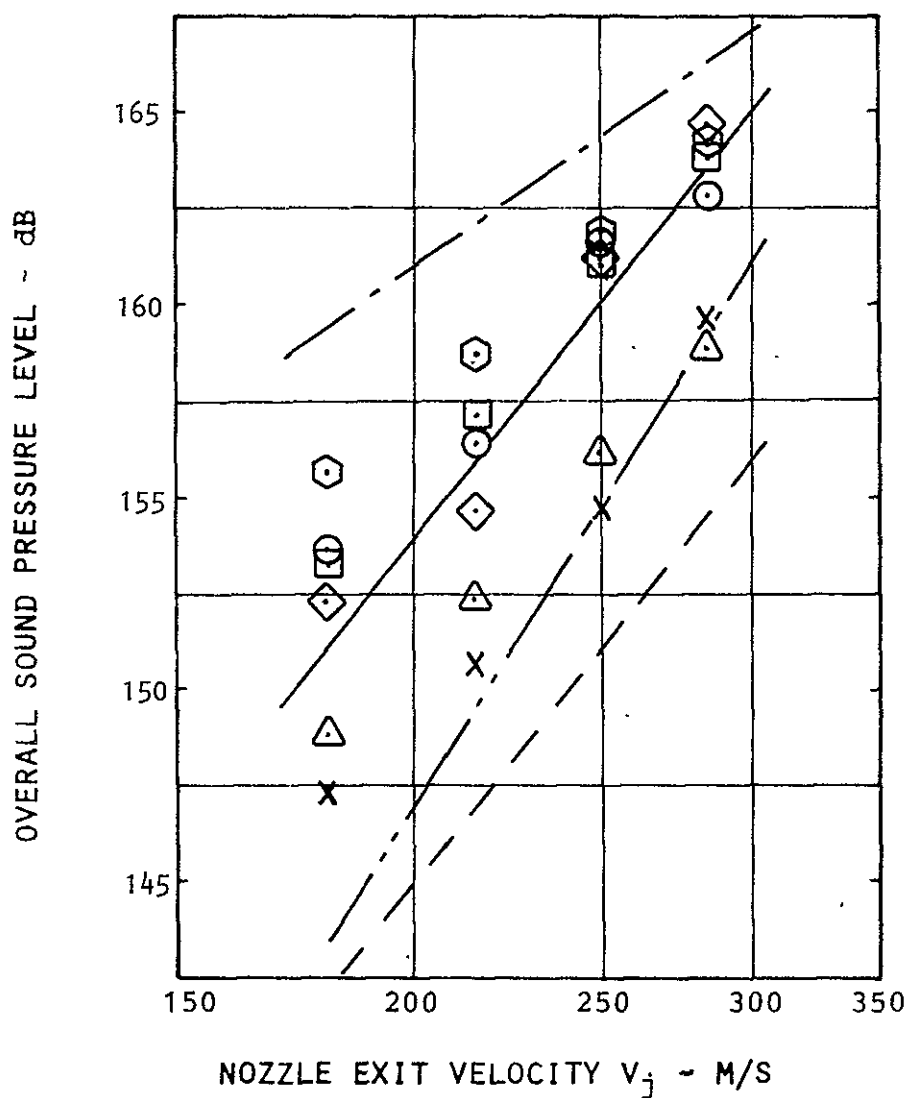
LARGE-SCALE BASELINE (TABLE 4-1)

LOCKHEED DATA $\delta_f = 60^\circ$

- AR8 POS 1
- AR8 POS 3
- △ AR8 POS 4
- ◇ AR4 POS 1
- AR4 POS 3
- × AR4 POS 4

REF. 7 DATA

- MODEL FLAP
- MODEL WING
- - - F.S. FLAP KNEE (34)
- - - F.S. NOZZLE EXIT (32)



a) OVERALL SOUND PRESSURE LEVELS

FIGURE 4-121. COMPARISON OF SURFACE FLUCTUATING PRESSURES WITH OTHER DATA

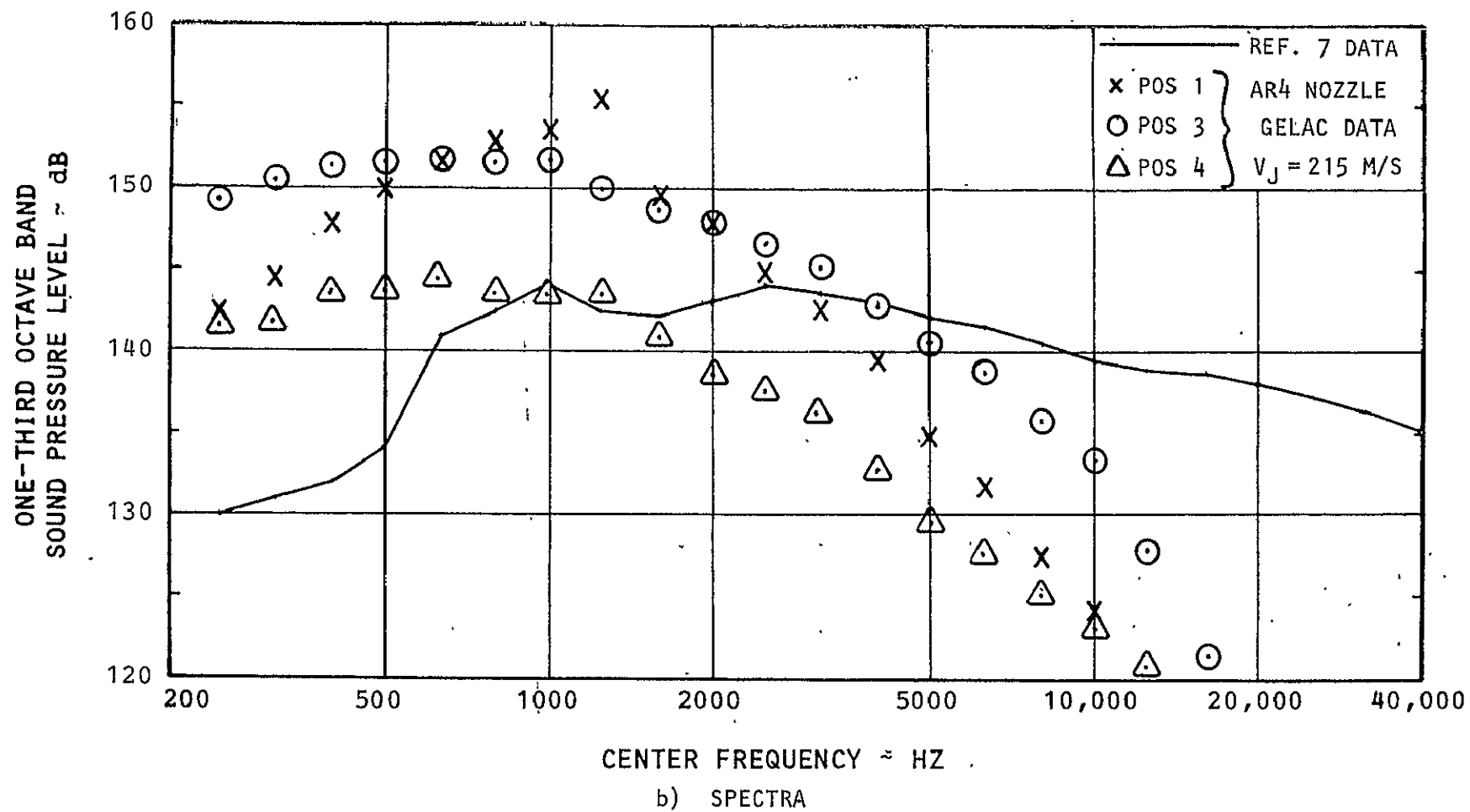


FIGURE 4-121.. (CONCLUDED)

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